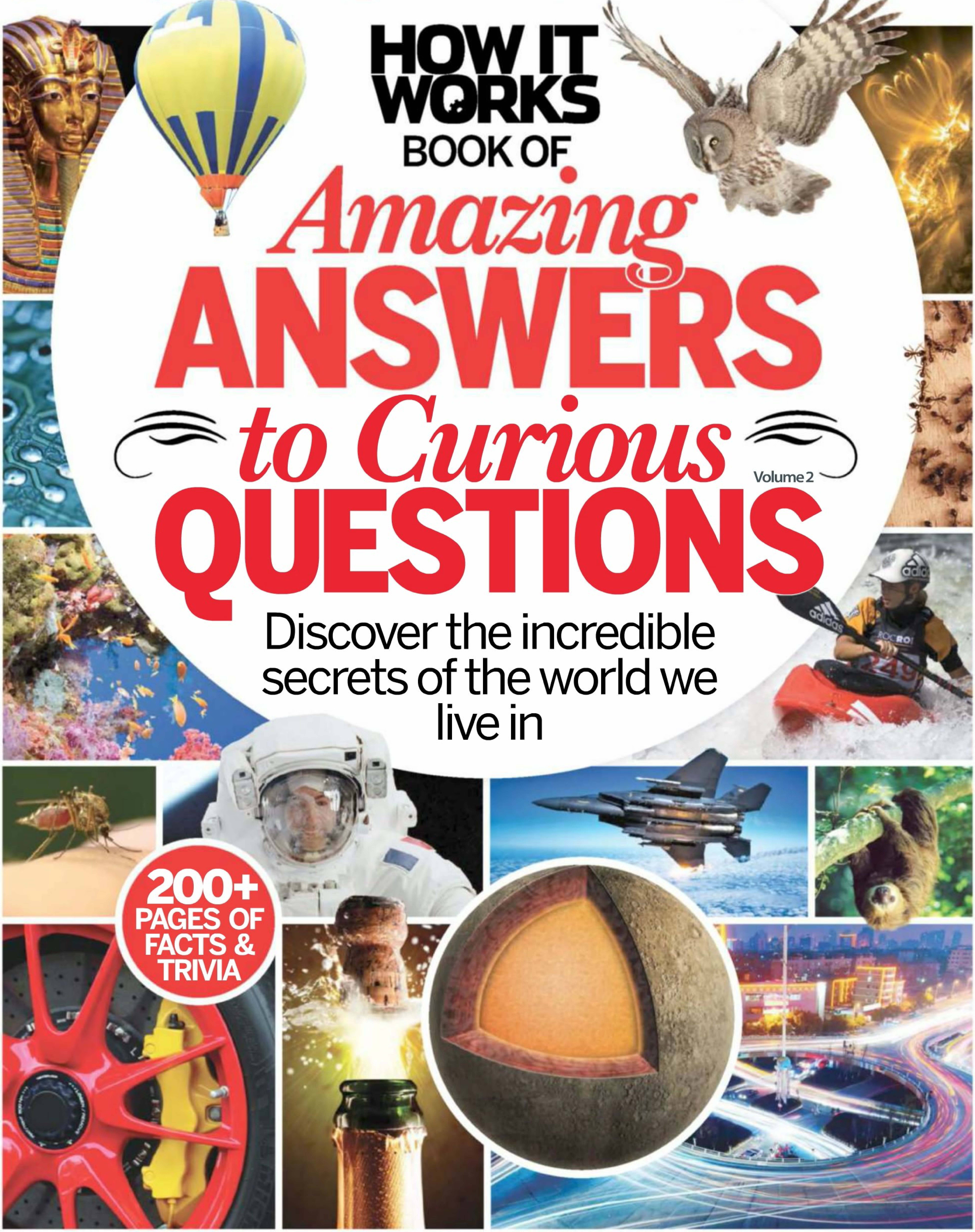
SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

HOW IT WORKS BOOK OF *Amazing* ANSWERS *to Curious* QUESTIONS

Volume 2

Discover the incredible secrets of the world we live in



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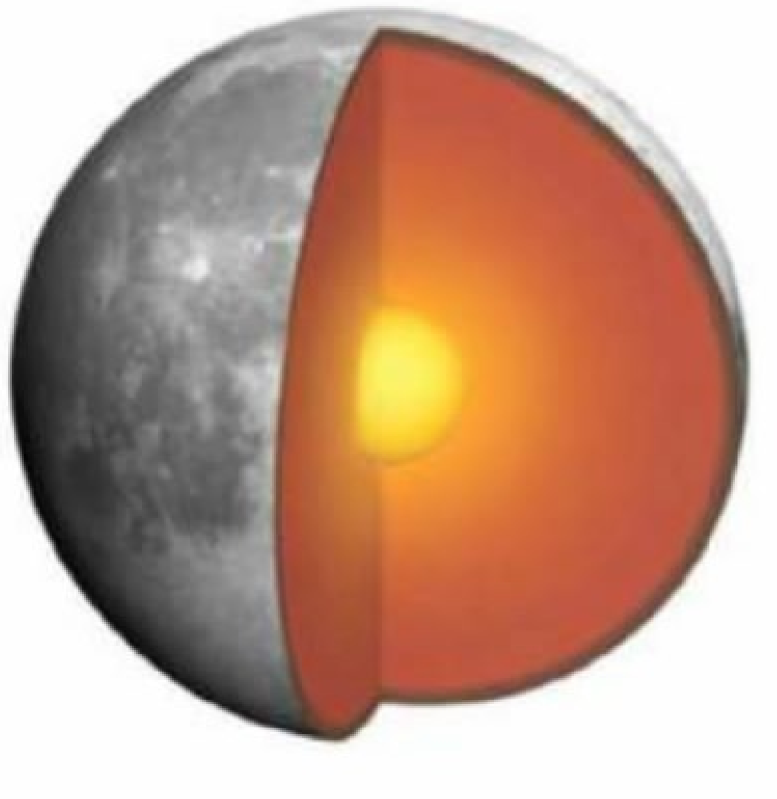
If you're curious about the world we live in, then you've come to the right place. Packed with fascinating answers to some of life's most interesting – and bizarre – questions, the How It Works Book of Amazing Answers to Curious Questions Volume 2 will educate, enlighten, and entertain. Perfect for people of all ages, you'll find plenty of amazing subjects, covering science, the environment, history, technology, transport and space. If you've ever wondered what makes us sneeze, how killer whales hunt, what caused the destruction of Pompeii, how paper is made, what life jackets are made of, or why the Earth spins, you'll find all the answers you're looking for right here.



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HOW IT WORKS
BOOK OF
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Imagine Publishing Ltd
Richmond House
33 Richmond Hill
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Dorset BH2 6EZ
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Twitter: @Books_Imagine
Facebook: www.facebook.com/ImagineBookazines

Head of Publishing
Aaron Asadi

Head of Design
Ross Andrews

Production Editor
Jon White

Senior Art Editor
Danielle Dixon

Design
Sarah Bellman

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IMAGINEER OF THE YEAR
DANIELLE DIXON

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BOOKAZINES

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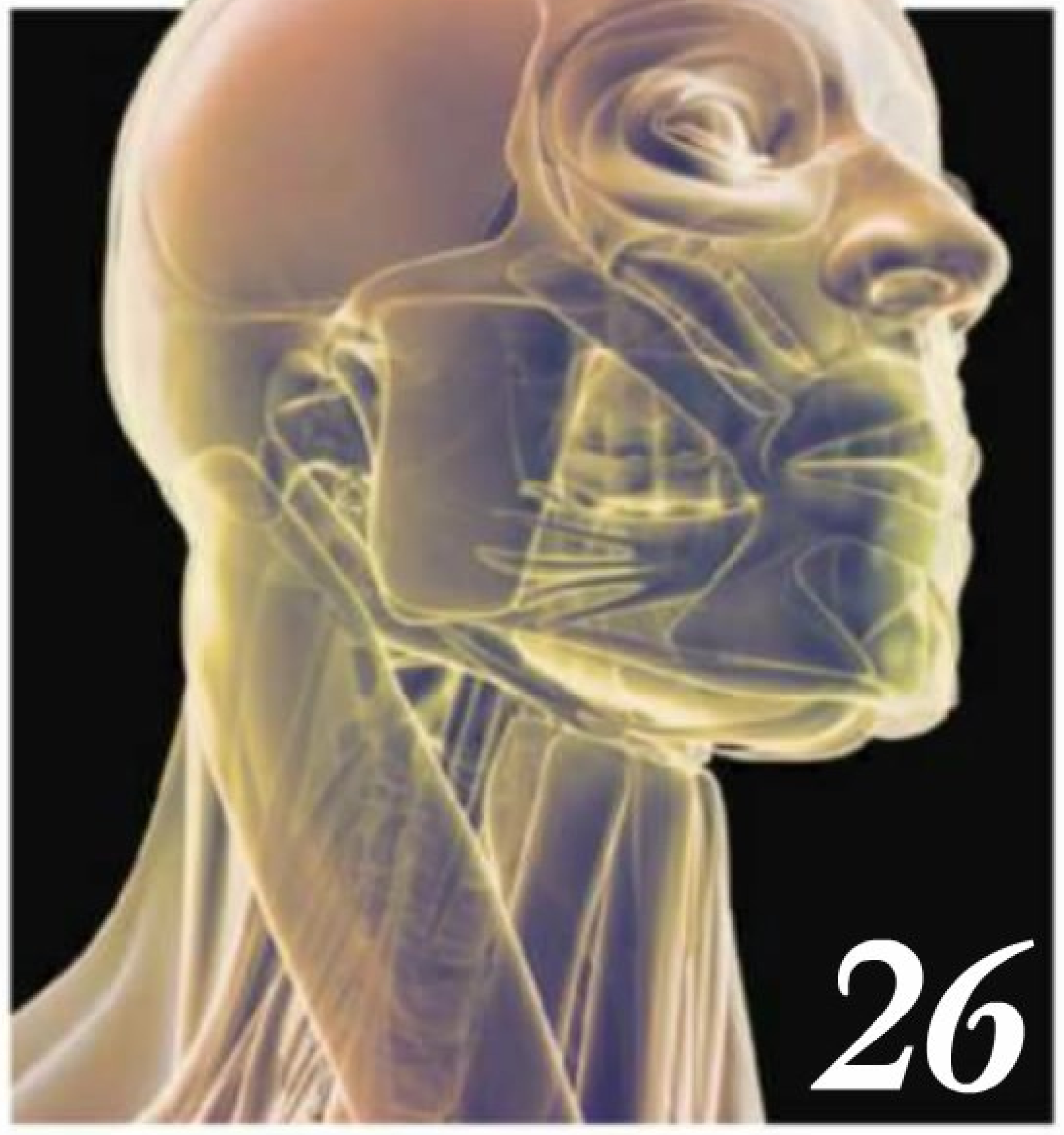

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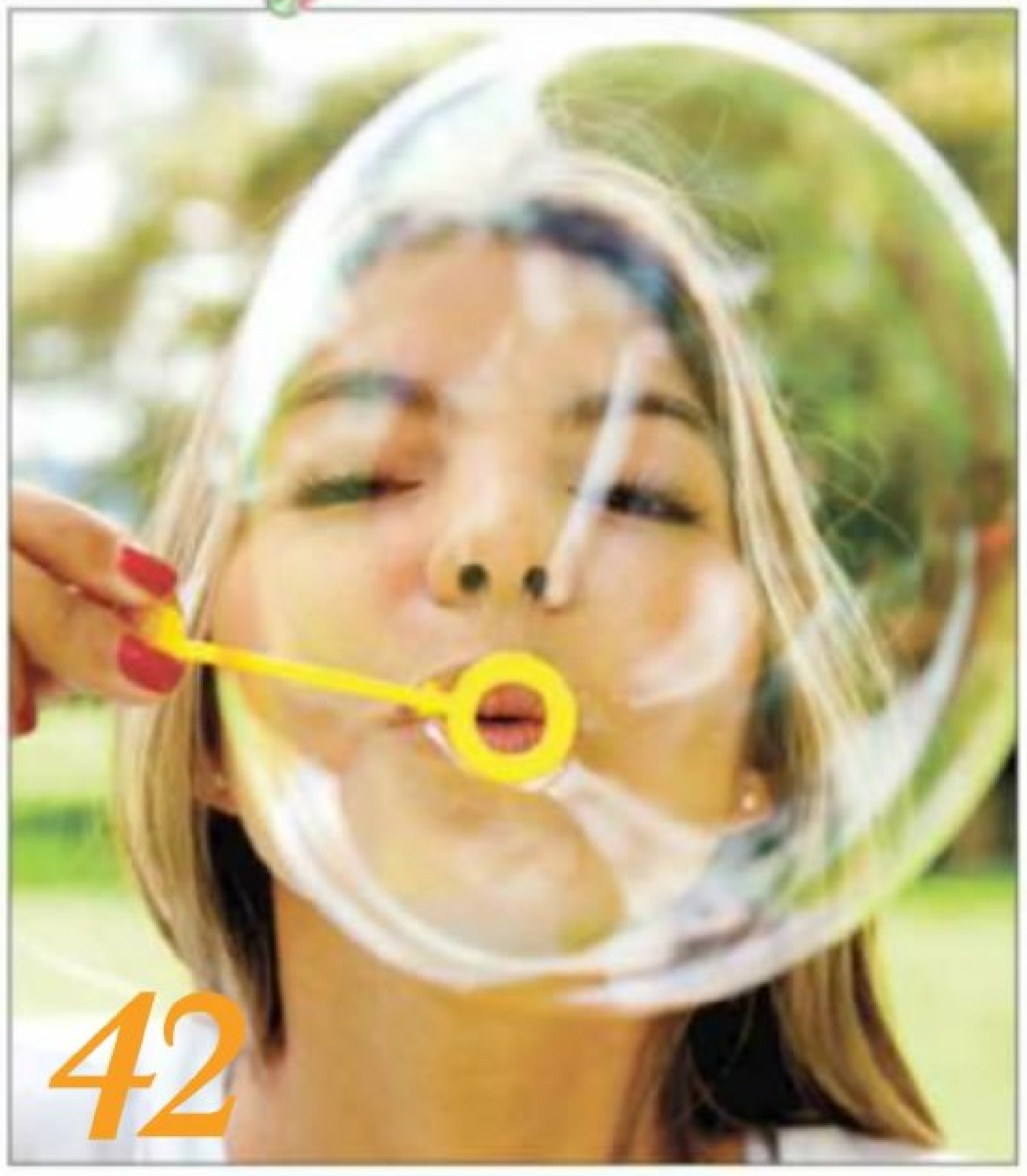

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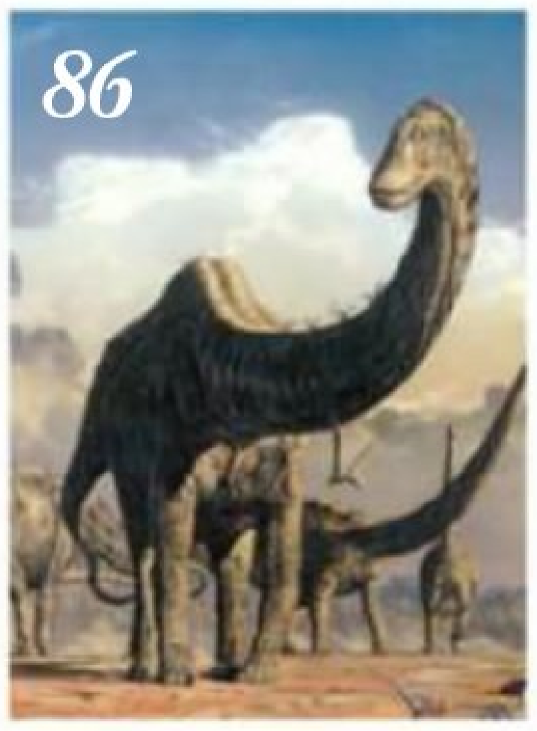

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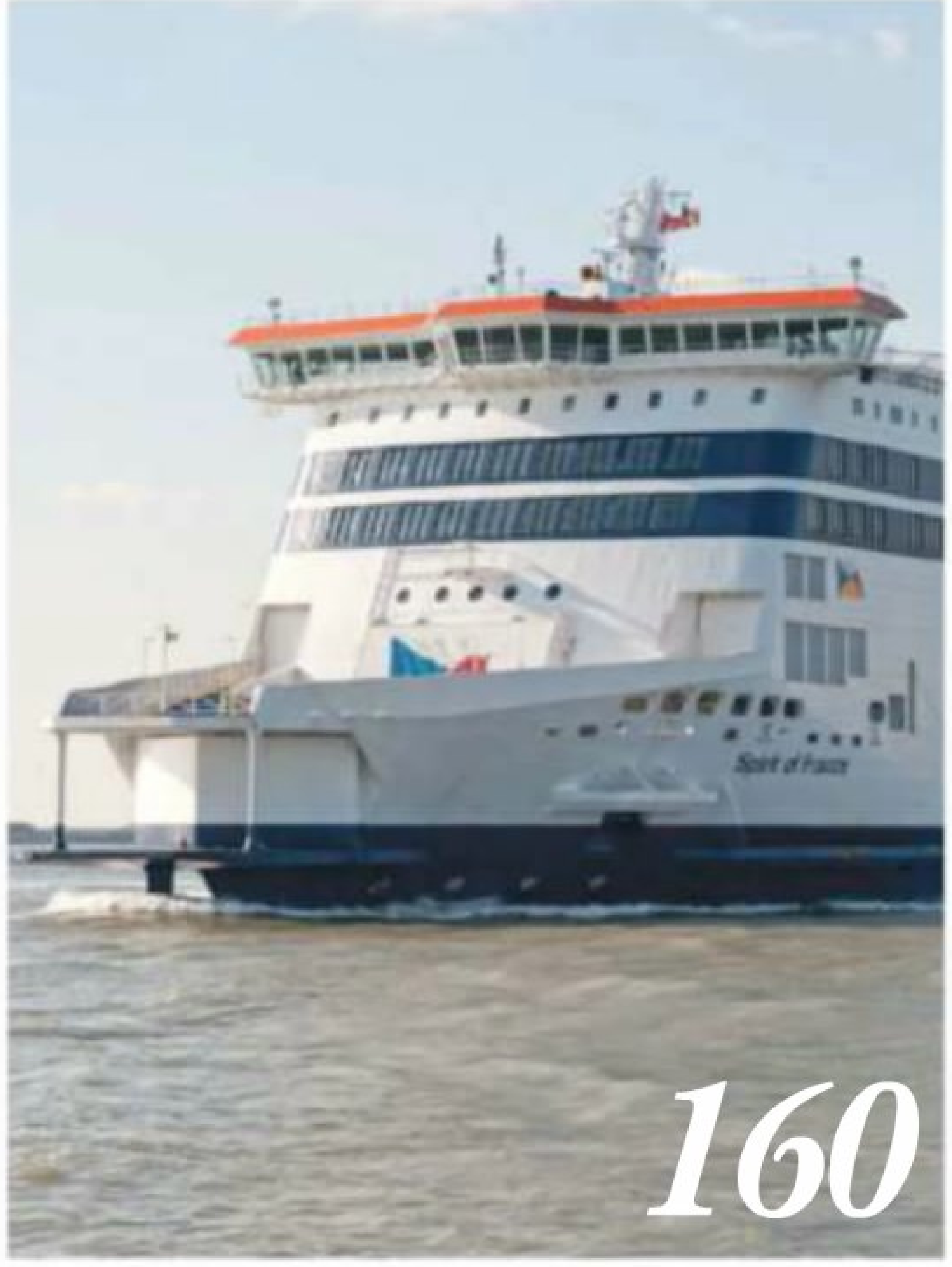
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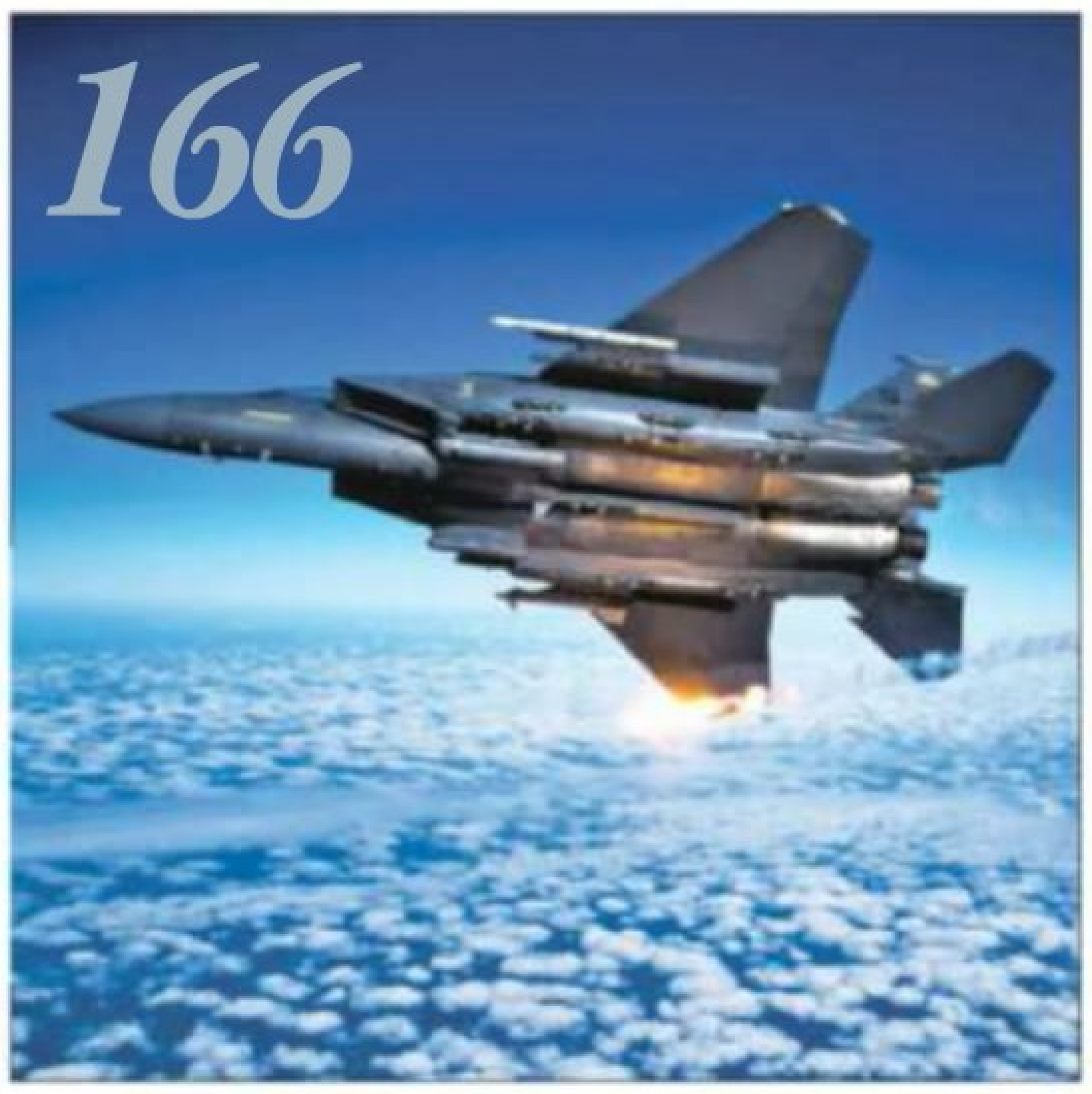

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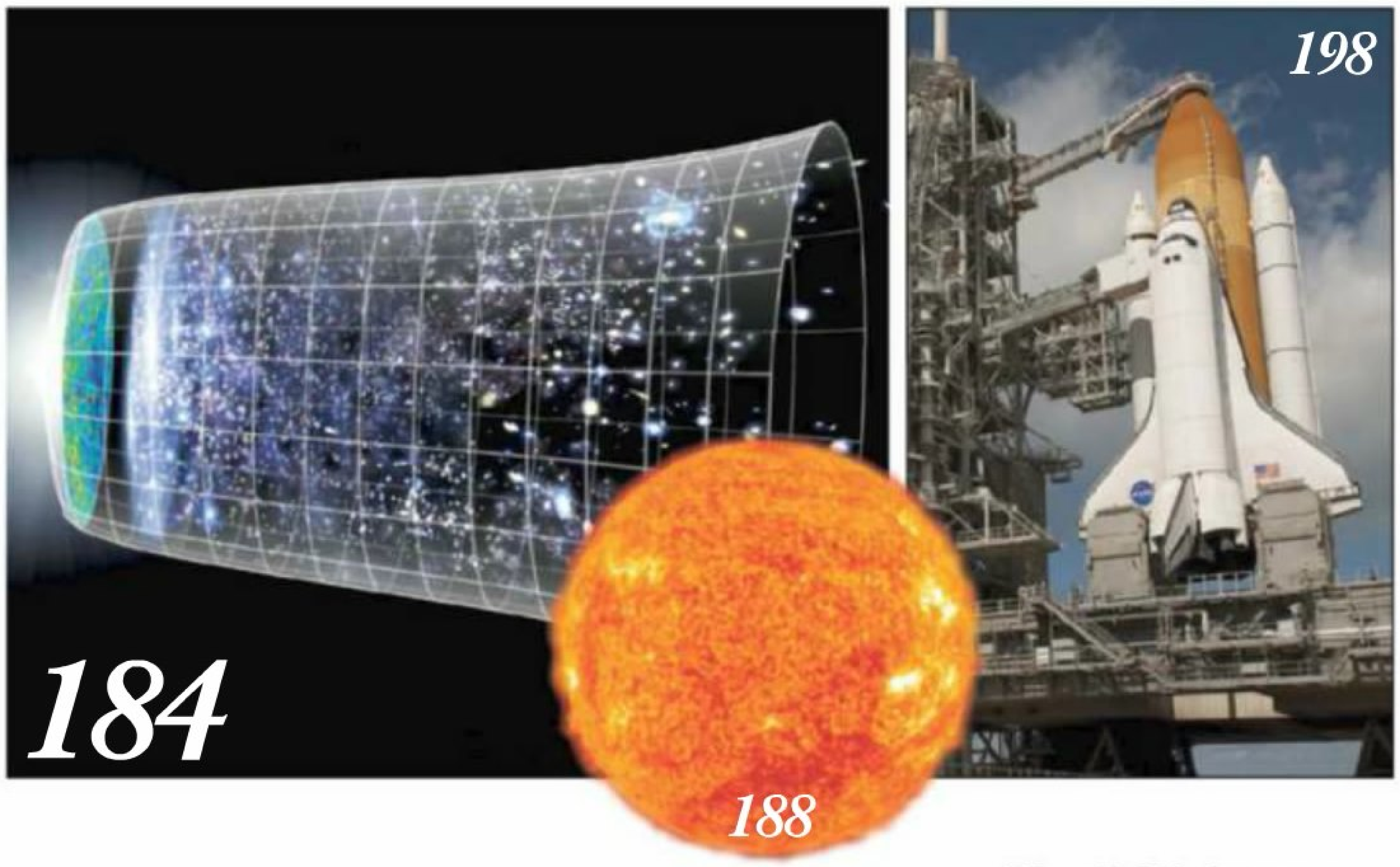

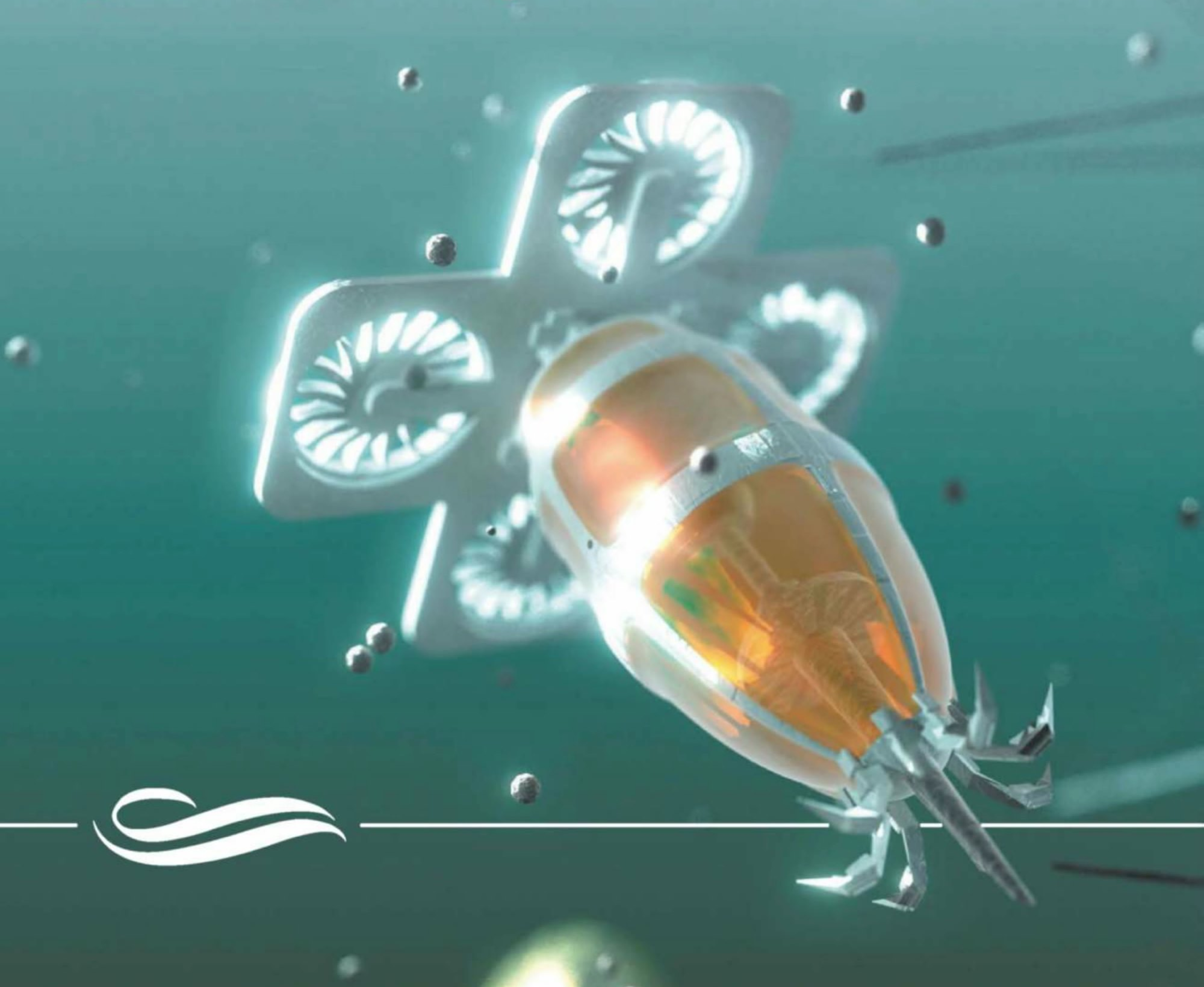

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What is the secret of cell division?

Like parent, like child – every multi-celled organism started out as a single cell

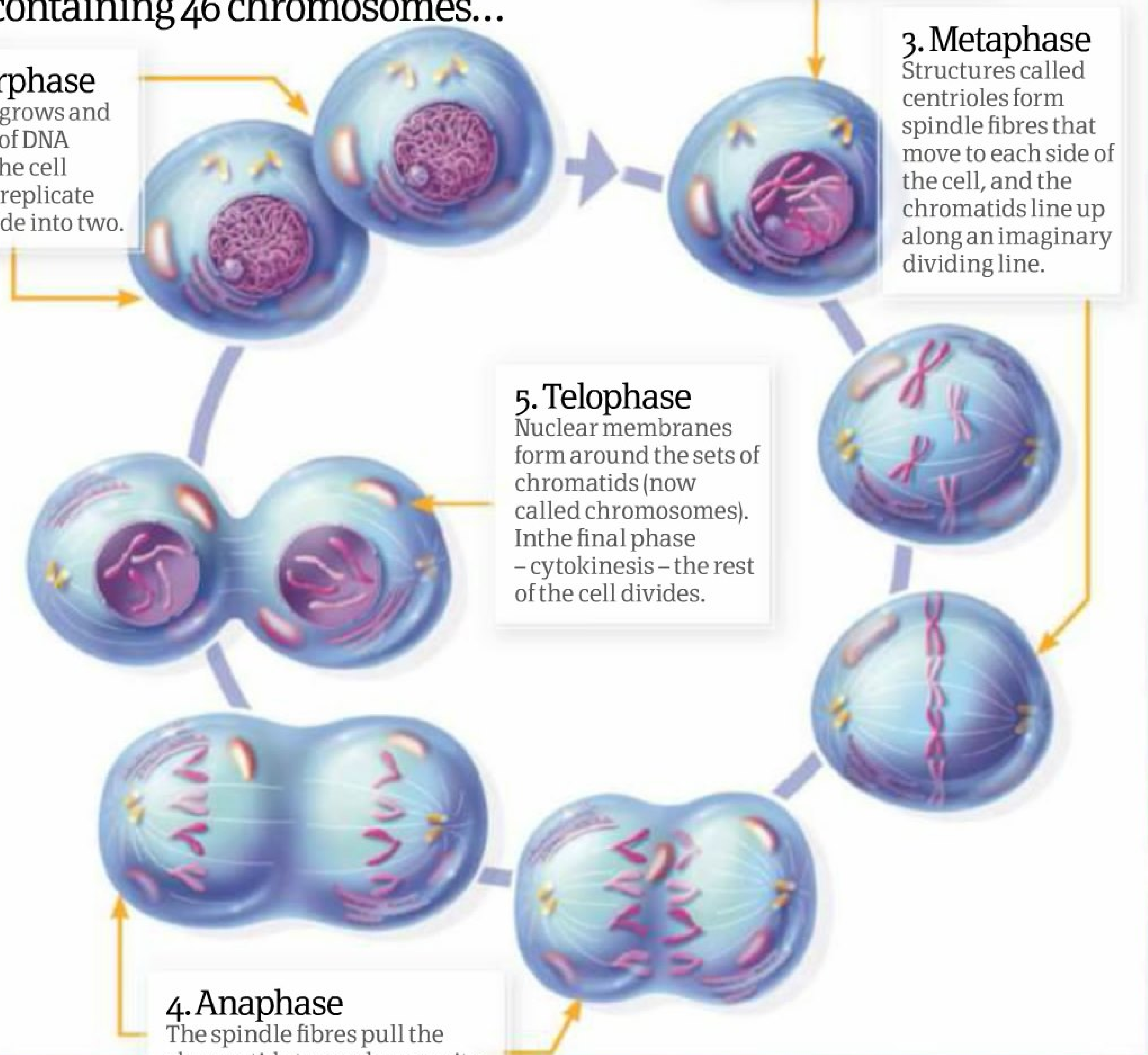
There's an old joke that goes, 'Let's make like an amoeba and split'. Every organism goes through cell division, although in the case of the humble amoeba, cell division means creating another amoeba. Amoebas are a type of cell known as a prokaryote (which also includes things like bacteria). It doesn't have a nucleus, but has its DNA and other genetic material floating around inside the cell. It reproduces asexually through binary fission or a process called budding.

On the other hand, us humans – and every other multi-celled organism in existence – are quite a bit more complicated. As eukaryotes, our cells undergo two different types of cell division depending on the type of cell: meiosis and mitosis. Both are complex, multi-step processes that happen very quickly. In order to sexually reproduce, our bodies create special sex cells called gametes (in animals we call these sperm in males, and eggs in females). Gametes are haploid cells because they contain 23 chromosomes, which are considered a single set. During reproduction, they merge to form a cell containing 46 chromosomes, called a diploid. But first, meiosis splits the original diploid cells, with the chromosomes duplicating, shuffling and reforming into four unique haploid cells.

In contrast, mitosis produces two identical haploid cells. It's a different process from the prokaryotic asexual reproduction, but in humans and other multi-celled organisms it's a sort of maintenance programme. Your body is undergoing mitosis constantly as all sorts of cells die and are replaced. Each human has between 50 and 75 trillion different cells and about 200 different types of cell. ✽

Mitosis

Mitosis is the process by which our bodies replace cells. It starts with a diploid cell containing 46 chromosomes…



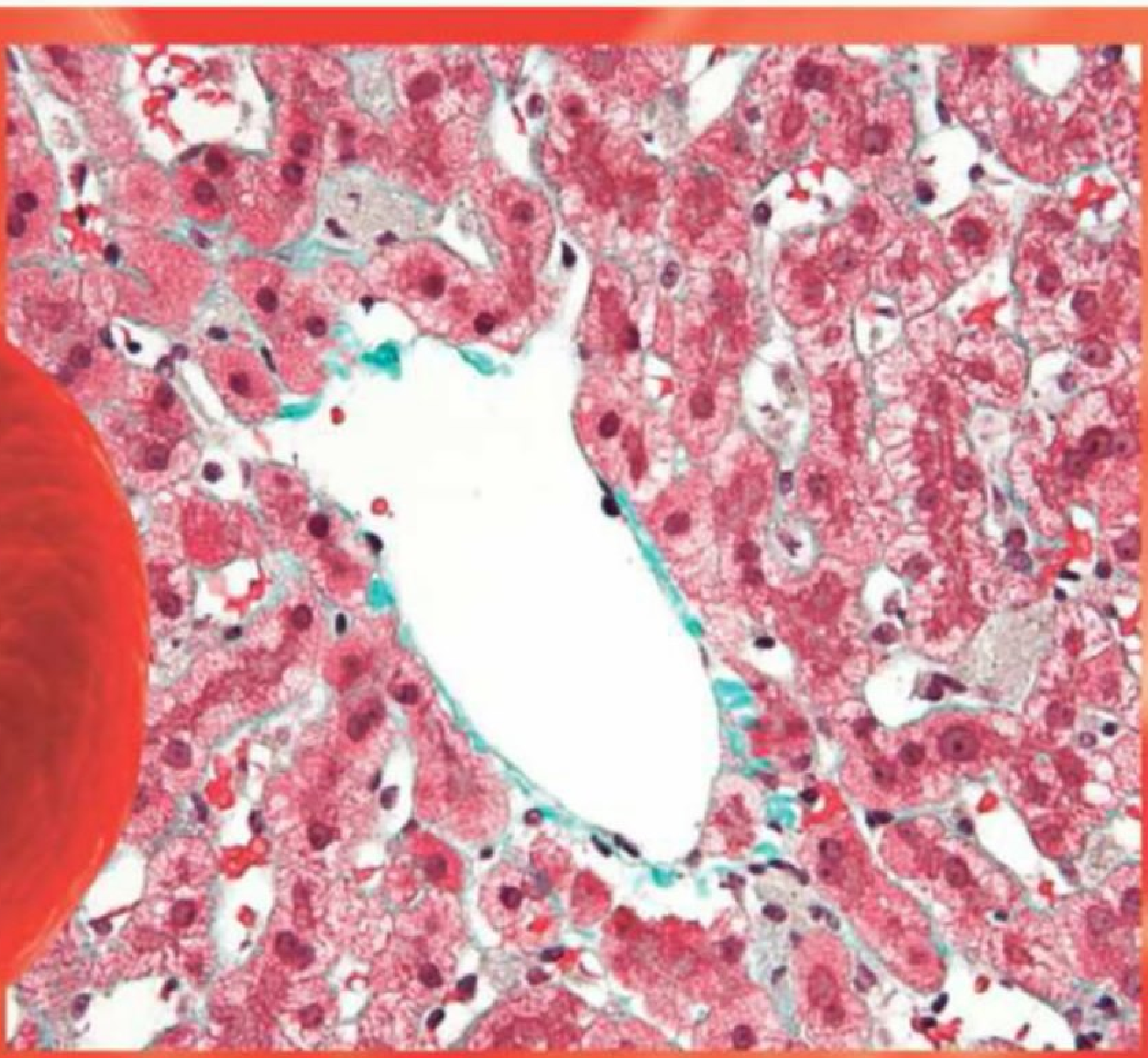
1. Interphase
The cell grows and strands of DNA within the cell nucleus replicate and divide into two.

2. Prophase
The 96 chromosomes consolidate into visible X-shaped structures called chromatids. The cell's nucleus begins to break down.

3. Metaphase
Structures called centrioles form spindle fibres that move to each side of the cell, and the chromatids line up along an imaginary dividing line.

4. Anaphase
The spindle fibres pull the chromatids towards opposite sides as the cell begins to split.

5. Telophase
Nuclear membranes form around the sets of chromatids (now called chromosomes). In the final phase – cytokinesis – the rest of the cell divides.



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A normal cell in humans can only divide 52 times before dying, known as the Hayflick limit

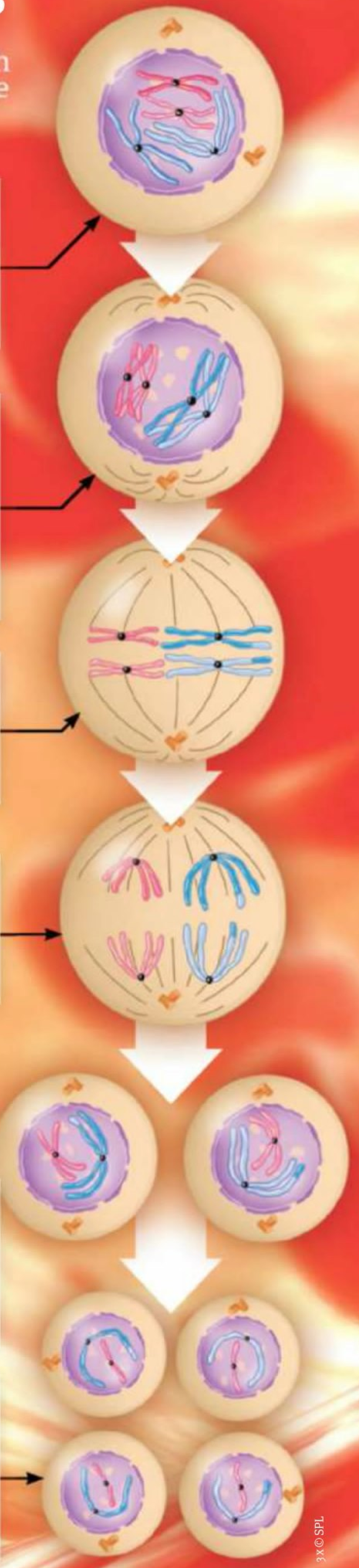
> "As eukaryotes, our cells undergo two different types of cell division"

Tumours

Tumours can be malignant (cancerous) or non-malignant, and at their most basic are the result of abnormal cell growth. The nucleus of every cell contains material that tells the cell when it's time to grow and divide (mitosis). There's a strict balance so that the new healthy cells are always replacing old, dying or damaged cells. Sometimes, however, cells get the message to grow and divide more often than they're supposed to, throwing off the equilibrium. Typically this comes from a genetic mutation – that is, there's a problem with the programming. These genetic mutations can be caused by anything from environmental factors to viruses. In cancerous tumours, the cells don't die like normal cells – instead, the mutation allows them to replicate indefinitely.

Meiosis

Meiosis is the process by which our bodies create sex cells so we can reproduce



1. Parent cell
Meiosis starts the same way as mitosis – with a diploid cell containing 46 chromosomes. The DNA strands replicate and divide.

2. Prophase
The chromosomes match up with their corresponding strand. Enzymes remove pieces of DNA from each and genes swap between the chromosomes before re-pairing.

3. Metaphase
At this point, unlike in mitosis, chromosome pairs line up on either side of an imaginary line in the cell.

4. Anaphase
Next, the chromosome pairs separate, with half moving to one side and half moving to the other.

5. Telophase
Nuclei start to form around each chromosome as the cell divides into two daughter cells, each with 46 chromosomes.

6. Daughter cells
The two daughter cells go through the entire process again, ultimately forming four daughter cells, each with 23 chromosomes.

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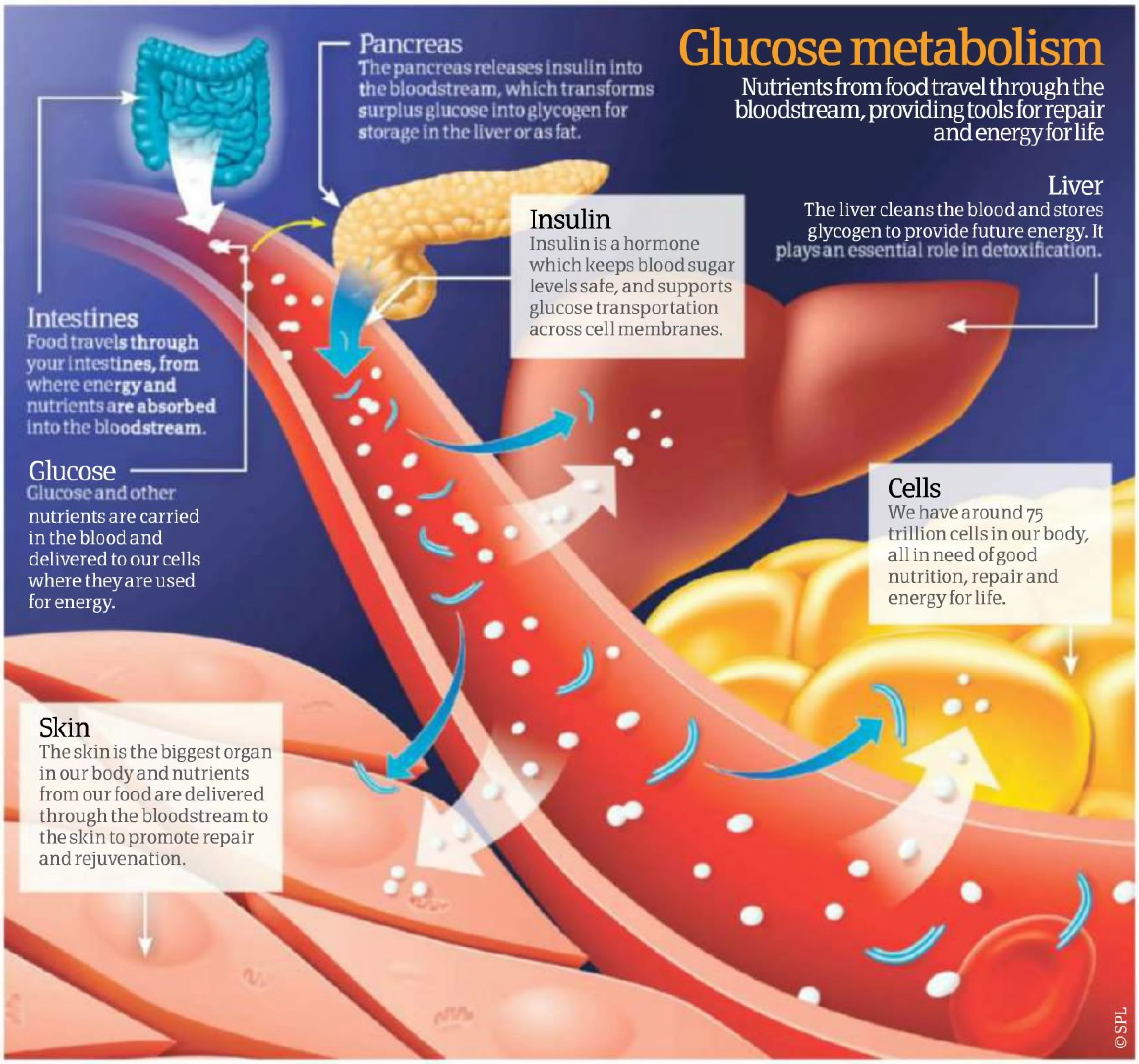


Glucose metabolism

Nutrients from food travel through the bloodstream, providing tools for repair and energy for life

Pancreas
The pancreas releases insulin into the bloodstream, which transforms surplus glucose into glycogen for storage in the liver or as fat.

Insulin
Insulin is a hormone which keeps blood sugar levels safe, and supports glucose transportation across cell membranes.

Liver
The liver cleans the blood and stores glycogen to provide future energy. It plays an essential role in detoxification.

Intestines
Food travels through your intestines, from where energy and nutrients are absorbed into the bloodstream.

Glucose
Glucose and other nutrients are carried in the blood and delivered to our cells where they are used for energy.

Cells
We have around 75 trillion cells in our body, all in need of good nutrition, repair and energy for life.

Skin
The skin is the biggest organ in our body and nutrients from our food are delivered through the bloodstream to the skin to promote repair and rejuvenation.

© SPL

How fast is your metabolism?

Metabolism doesn't just affect your ability to gain or lose weight

The basal metabolic rate (BMR) measures how fast a person's body uses energy (in calories) while at rest. If you eat too many calories, the body will store the energy as fat for later use. Those with a low BMR burn fewer calories while at rest and will have a tendency to gain weight.

Hormones play a key role in metabolism – eg thyroxine is a hormone produced by the thyroid gland which affects the speed of metabolism. An overactive thyroid can result in energy being used too fast, resulting in hyperactivity and weight loss. Insulin is released by the pancreas in response to elevated blood glucose – usually after meals. It pushes blood sugar into the cells and triggers an increase in anabolic activities.

It's common for people to blame a slow metabolism for their weight problems, but usually this is untrue and more likely a result of poor diet and lifestyle choices.

How does metabolism work?

Discover why a healthy metabolism is vital

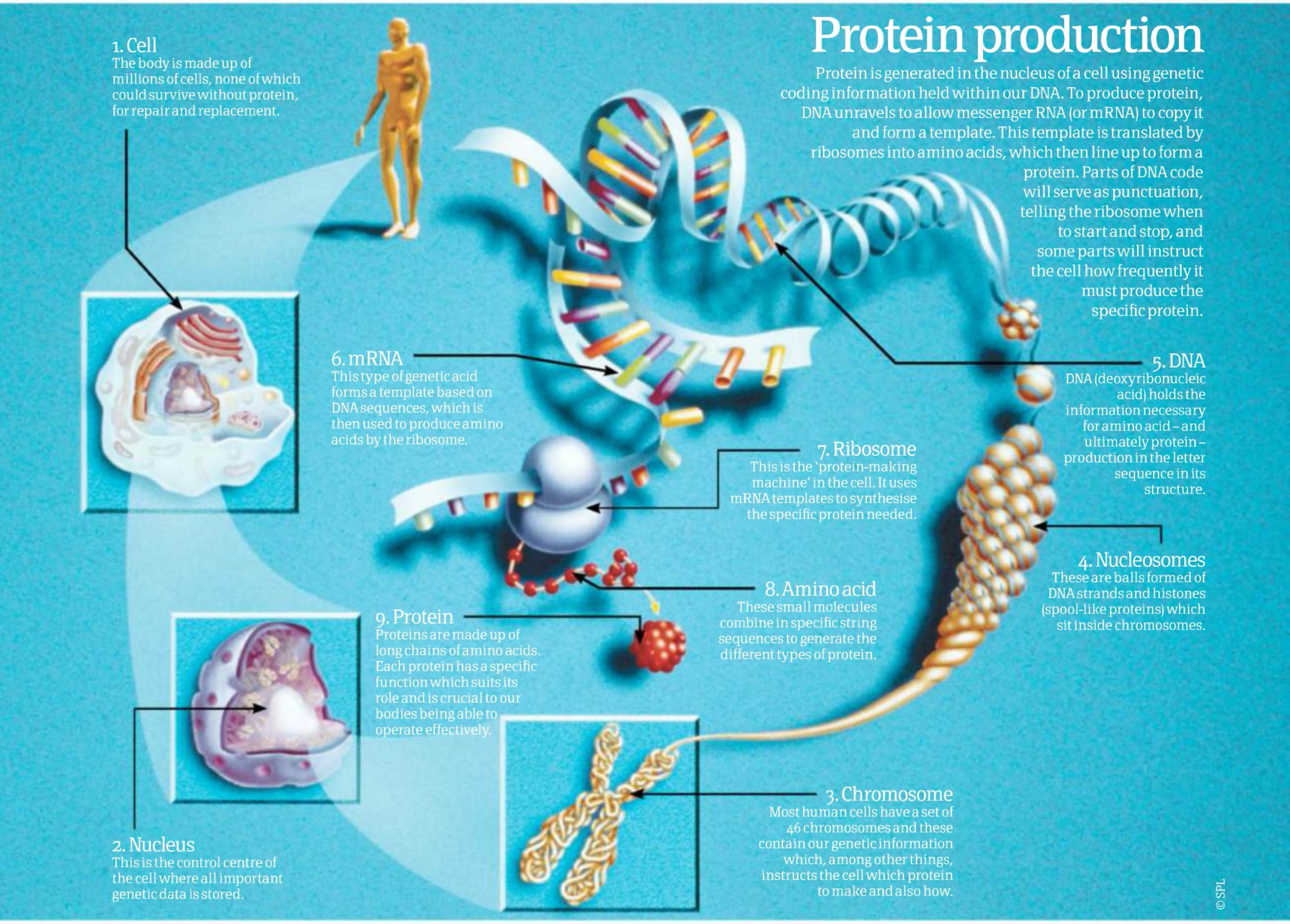
Metabolism is a series of chemical reactions in the body, which convert the food we eat into the energy that we use for growth, movement and healing. Metabolic reactions occur simultaneously to keep us healthy.

Metabolism begins with plants and photosynthesis – the process whereby a plant absorbs energy from sunlight enabling it to create sugars from water and carbon dioxide. We eat the plants, taking in this energy as carbohydrates, which release glucose into the bloodstream to fuel the body. Digestive enzymes break protein from food down into its individual constituents, called amino acids. Fats are converted into fatty acids, and carbohydrates become sugars, all of which are slowly released into the bloodstream as part of the digestive process.

These nutrients enter the body's cells through the blood and are used either to power the body, build muscle and repair damage or are stored for later use. So the process of metabolism is the building up of tissues, muscle and energy stores and the breaking down of energy stores and fat to generate energy when it is required.

Anabolism (constructive metabolism) is all about building and storing: it supports the growth of brand-new cells, the maintenance of body tissues and the storage of energy for use in the future.

The reverse is catabolism (destructive metabolism), which produces energy for cellular activity. Catabolism releases glucose, mostly from carbohydrates and stored fat, which provides energy to heat the body and enable movement on demand.



Protein production

Protein is generated in the nucleus of a cell using genetic coding information held within our DNA. To produce protein, DNA unravels to allow messenger RNA (or mRNA) to copy it and form a template. This template is translated by ribosomes into amino acids, which then line up to form a protein. Parts of DNA code will serve as punctuation, telling the ribosome when to start and stop, and some parts will instruct the cell how frequently it must produce the specific protein.

1. Cell
The body is made up of millions of cells, none of which could survive without protein, for repair and replacement.

2. Nucleus
This is the control centre of the cell where all important genetic data is stored.

3. Chromosome
Most human cells have a set of 46 chromosomes and these contain our genetic information which, among other things, instructs the cell which protein to make and also how.

4. Nucleosomes
These are balls formed of DNA strands and histones (spool-like proteins) which sit inside chromosomes.

5. DNA
DNA (deoxyribonucleic acid) holds the information necessary for amino acid – and ultimately protein – production in the letter sequence in its structure.

6. mRNA
This type of genetic acid forms a template based on DNA sequences, which is then used to produce amino acids by the ribosome.

7. Ribosome
This is the 'protein-making machine' in the cell. It uses mRNA templates to synthesise the specific protein needed.

8. Amino acid
These small molecules combine in specific string sequences to generate the different types of protein.

9. Protein
Proteins are made up of long chains of amino acids. Each protein has a specific function which suits its role and is crucial to our bodies being able to operate effectively.

© SPL

How do we make protein?

Proteins are the building blocks of the body, but how do we manufacture them?

Proteins are large complex molecules made up of a chain of amino acids. Every cell in our body needs protein to stay alive as it is necessary for tissue repair and replacing dead cells.

They have many other functions as well as aiding cell repair and production including forming antibodies to help fight off disease, forming enzymes which speed up or trigger chemical reactions and co-ordinating processes within the body (via hormone regulation, for instance). Proteins also provide support for cells and form structural elements of the body, such as nails and teeth, as well as facilitating the transportation of some small molecules around various systems.

We build proteins using information encoded in our genetic code. DNA code utilises groups of three letters (a mix of A, G, C and T) and these short sequences, which are known as triplets or codons, then code mRNA templates; these templates are 'translated' by cvell ribosomes into amino acids.

Each protein is made up of hundreds of thousands of amino acids, which are in long chains. There are 20 different types of amino acid that can be combined to build a protein and it is the sequence of amino acids that determines each protein's unique three-dimensional structure and its function.

However, not all amino acids can be made by the body itself. The ones that need to be consumed via our diet are called essential amino acids. If possible, the body will also conserve energy by using amino acids from food rather than producing them itself. Protein deficiency can cause diseases such as kwashiorkor, a form of malnutrition that is common in poverty-stricken areas.

When you've got to go, you've got to go… but really our bodies are reacting to our bladders' direction

What does your bladder do?

As a key part of the urinary system, the bladder is crucial to removing waste from your body

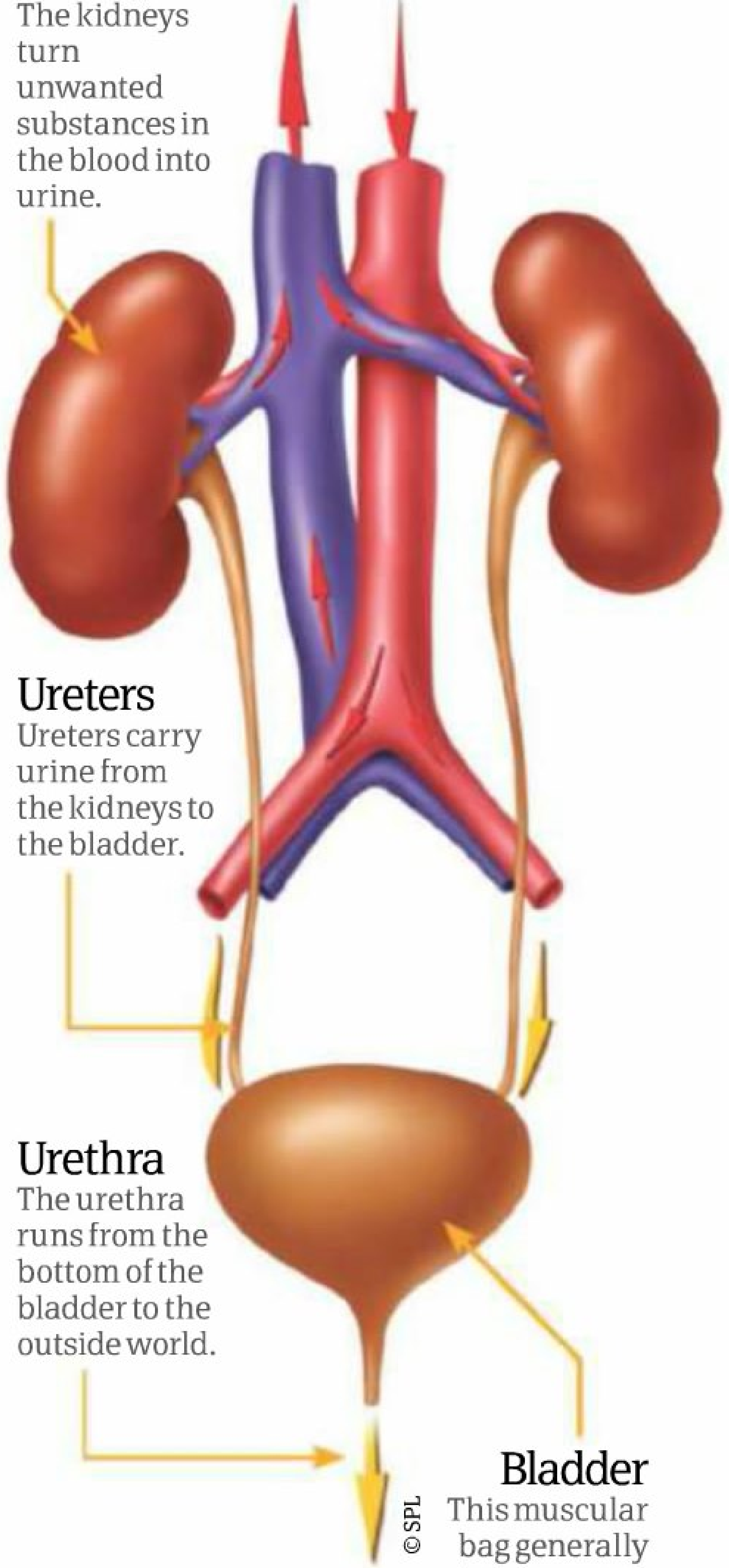
The bladder is one of the key organs in the urinary system and it stores urine following production by the kidneys until the body can release it.

Urine is a waste substance produced by the kidneys as they filter our blood of toxins and other unneeded elements. Up to 150 litres (40 gallons) of blood are filtered per day by your kidneys, but only around two litres (0.5 gallons) of waste actually pass down the ureters to the bladder.

Urine travels down the ureters and through the ureter valves, which attach each tube to the organ and prevent any liquid passing back. The bladder walls, controlled by the detrusor muscles, relax as urine enters and allow the organ to fill. When the bladder becomes full, or nearly full, the nerves in the bladder communicate with the brain, which in turn induces an urge to urinate. This sensation will get stronger if you do not go – creating the 'bursting for a wee' feeling that you can experience. When ready to urinate, both the internal and external sphincters relax and the detrusor muscles in the bladder wall contract in order to generate pressure, forcing urine to pass down the urethra and exit the body.

As well as telling you when you need to pass fluid, the urinary system also helps to maintain your body's mineral and salt balance. For instance, when salts and minerals are too highly concentrated, you feel thirst to regain the balance.

The complete urinary system



Kidneys
The kidneys turn unwanted substances in the blood into urine.

Ureters
Ureters carry urine from the kidneys to the bladder.

Urethra
The urethra runs from the bottom of the bladder to the outside world.

Bladder
This muscular bag generally holds around a pint of urine.

© SPL

Incontinence explained

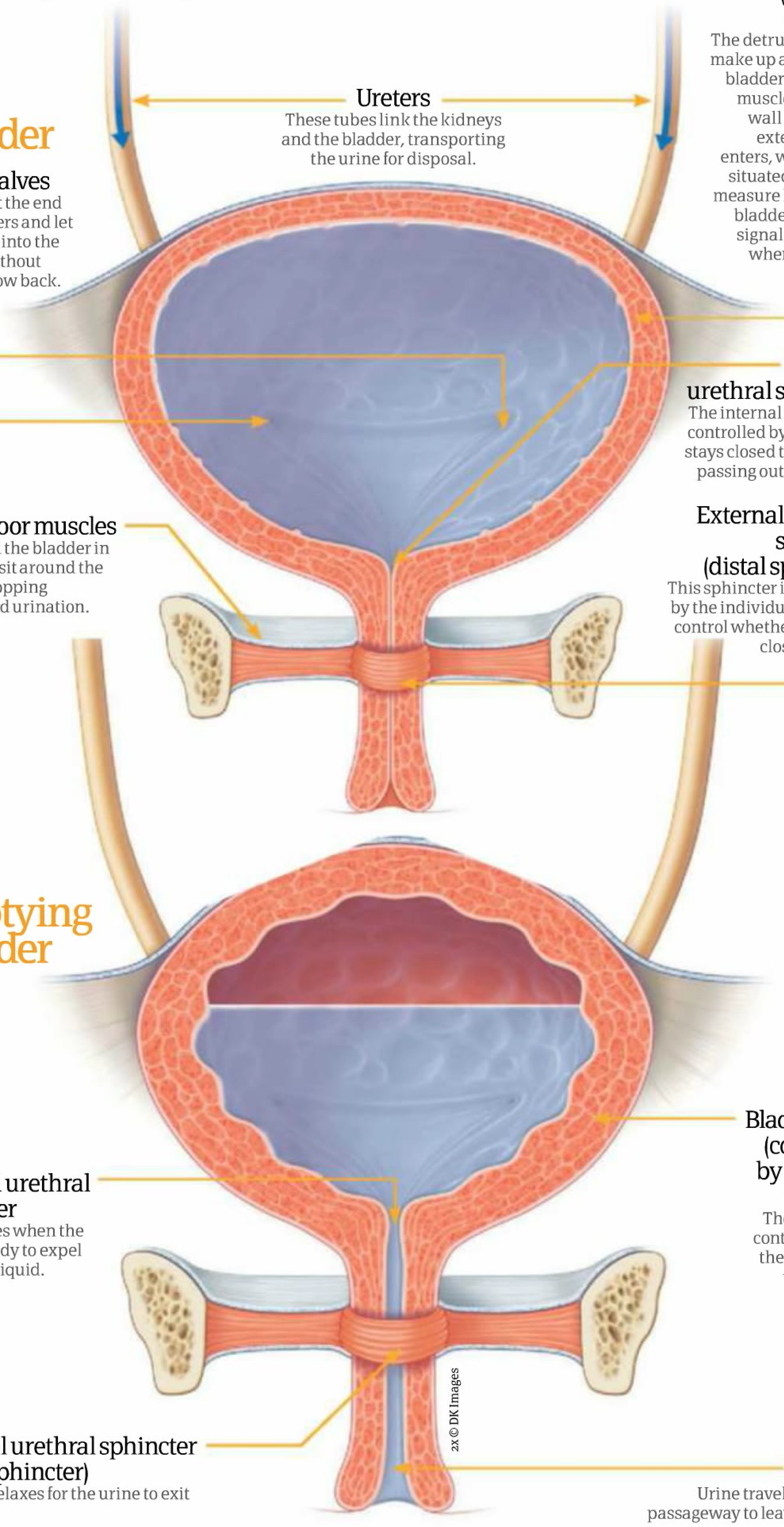
For the bladder to work correctly, several areas within it must all function properly. It is most commonly the failure of one of these features that leads to incontinence. A common type of urinary incontinence is urge incontinence. This is when an individual feels a sudden compulsion to urinate and will release urine without control. It is often caused by involuntary spasms by the detrusor muscles which can be a result of either nervous system problems or infections.

Another type is stress incontinence, caused when the external sphincter or pelvic floor muscles are damaged. This means urine can accidentally escape, especially if the pelvic floor is under pressure.

One modern remedy is a preventative implant that has been developed to replace post-event incontinence pads. This comes in the form of a collagen-based substance injected around the urethra in order to support it.

Inside the bladder

How this organ acts as the middleman between your kidneys and excretion



Full Bladder

Ureter valves
These sit at the end of the ureters and let urine pass into the bladder without letting it flow back.

Ureters
These tubes link the kidneys and the bladder, transporting the urine for disposal.

Bladder wall (detrusor muscles)
The detrusor muscles make up a layer of the bladder wall. These muscles cause the wall to relax and extend as urine enters, while nerves situated in the wall measure how full the bladder is and will signal to the brain when to urinate.

Internal urethral sphincter
The internal sphincter is controlled by the body. It stays closed to stop urine passing out of the body.

Pelvic floor muscles
These hold the bladder in place, and sit around the urethra stopping unintended urination.

External urethral sphincter (distal sphincter)
This sphincter is controlled by the individual, and they control whether to open or close the valve.

Emptying bladder

Bladder wall (controlled by detrusor muscles)
These muscles contract to force the urine out of the bladder.

Internal urethral sphincter
This relaxes when the body is ready to expel the waste liquid.

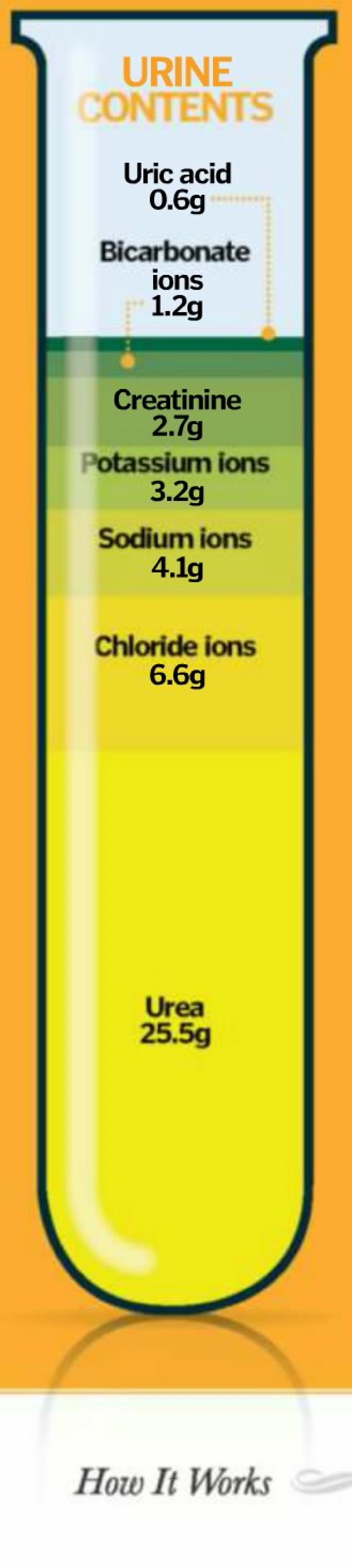
External urethral sphincter (distal sphincter)
This also relaxes for the urine to exit the body.

Urethra
Urine travels down this passageway to leave the body.

2x © DK Images

What is urine made up of?

A human bladder usually holds around 350 millilitres (0.7 pints) of urine, though male bladders can typically hold slightly more than those of females. Urine is made up of urea, the waste by-product the body forms while breaking down protein across the body. The kidneys will filter this out and pass it with extra water to the bladder for expulsion. Other waste products produced or consumed by the body that pass through the kidneys will also exit the body via this route. Typically, urine is made up of 95 per cent water and 5 per cent dissolved or suspended solids including urea, plus chloride, sodium and potassium ions.



Do you need a spleen?

Perhaps not as well known as famous organs like the heart, the spleen serves vital functions that help keep us healthy

The spleen's main functions are to remove old blood cells and fight off infection. Red blood cells have an average life span of 120 days. Most are created from the marrow of long bones, such as the femur. When they're old, it's the spleen's job to identify them, filter them out and then break them down. The smaller particles are then sent back into the bloodstream, and either recycled or excreted from other parts of the body. This takes place in the 'red pulp', which are blood vessel-rich areas of the spleen that make up about three-quarters of its structure. The remainder is called 'white pulp', which are areas filled with different types of immune cell. They filter out and destroy foreign pathogens, which have invaded the body and are circulating in the blood. The white pulp breaks them down into smaller, harmless particles.

The spleen is surrounded by a fragile capsule and so is prone to injury. It sits beneath the lower ribs on the left-hand side of your body, which affords it some protection, but car crashes, sports impacts and knife wounds can all rupture the organ. In the most serious cases, blood loss can endanger the person's life, and may need to be removed. Since this reduces the body's ability to fight infections, some people will need to take antibiotics to boost their immunity for the rest of their lives.

The immune system

Although the red blood that flows through our bodies gets all the glory, the transparent lymphatic fluid is equally important. It has its own body-wide network which follows blood vessel flow closely and allows for the transport of digested fats, immune cells and more…

Spleen

One of the master co-ordinators that staves off infections and filters old red blood cells. It contains numerous lymphocytes that recognise and destroy invading pathogens present in the blood as it flows through the spleen.

Thymus

A small organ that sits just above the heart and behind the sternum. It teaches T-lymphocytes to identify and destroy specific foreign bodies. Its development is directly related to hormones in the body so it's only present until puberty ends; adults don't need one.

Tonsils

These are masses of lymphoid tissue at the back of the throat and can be seen when the mouth is wide open. They form the first line of defence against inhaled foreign pathogens, although they can become infected themselves, causing tonsillitis.

Adenoids

These are part of the tonsillar system that are only present in children up until the age of five; in adults they have disappeared. They add an extra layer of defence in our early years.

Bone marrow

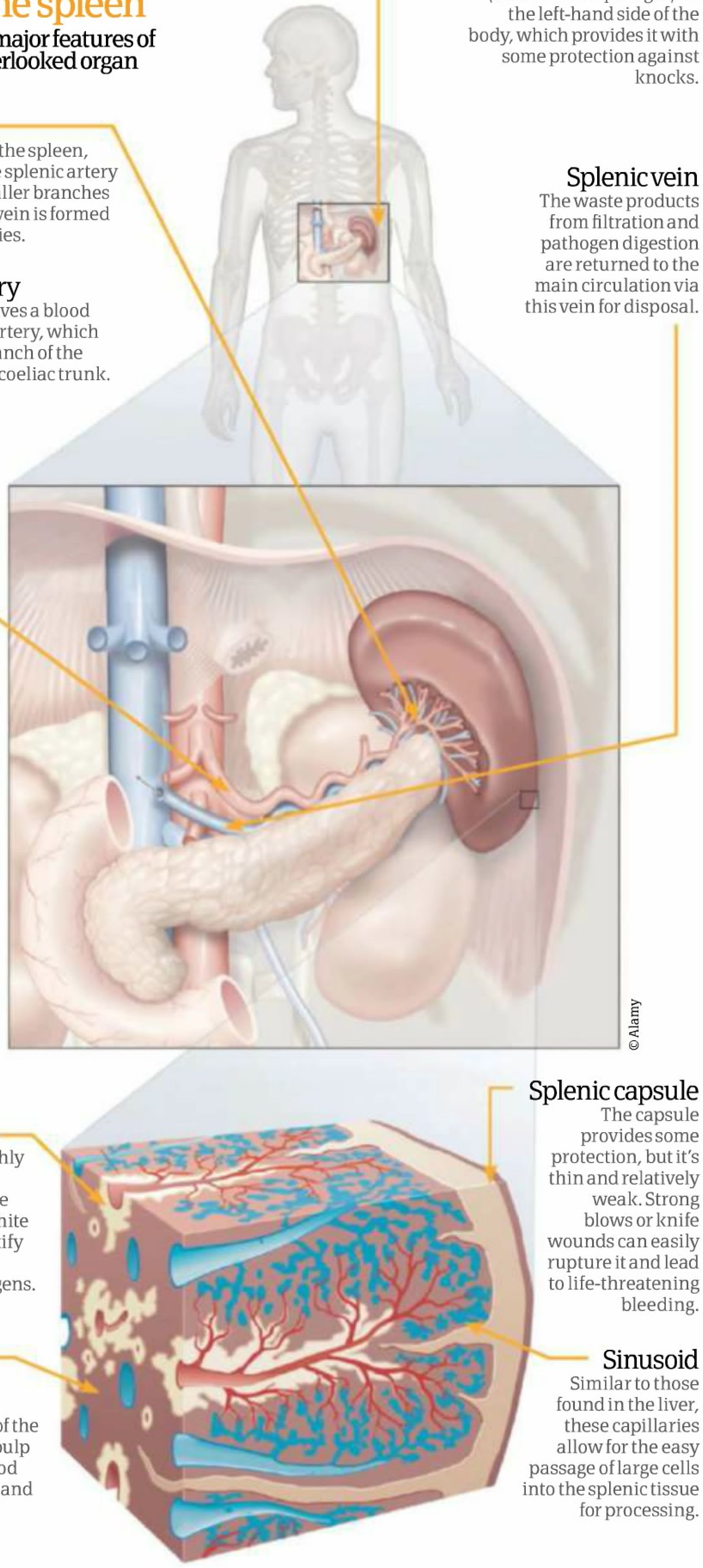
This forms the central, flexible part of our long bones (eg femur). Bone marrow is essential as it produces our key circulating cells, including red blood cells, white blood cells and platelets. The white blood cells mature into different types (eg lymphocytes and neutrophils), which serve as the basis of the human immune system.

Lymph nodes

These are small (about 1cm/0.4in) spherical nodes that are packed with macrophages and lymphocytes to defend against foreign agents. These are often linked in chains and are prevalent around the head, neck, axillae (armpits) and groin.

Inside the spleen

Discover the major features of this often-overlooked organ



© Alamy

Location
The spleen sits underneath the 9th, 10th and 11th ribs (below the diaphragm) on the left-hand side of the body, which provides it with some protection against knocks.

Hilum
The entrance to the spleen, this is where the splenic artery divides into smaller branches and the splenic vein is formed from its tributaries.

Splenic artery
The spleen receives a blood supply via this artery, which arises from a branch of the aorta called the coeliac trunk.

Splenic vein
The waste products from filtration and pathogen digestion are returned to the main circulation via this vein for disposal.

White pulp
Making up roughly a quarter of the spleen, the white pulp is where white blood cells identify and destroy invading pathogens.

Red pulp
Forming approximately three-quarters of the spleen, the red pulp is where red blood cells are filtered and broken down.

Splenic capsule
The capsule provides some protection, but it's thin and relatively weak. Strong blows or knife wounds can easily rupture it and lead to life-threatening bleeding.

Sinusoid
Similar to those found in the liver, these capillaries allow for the easy passage of large cells into the splenic tissue for processing.

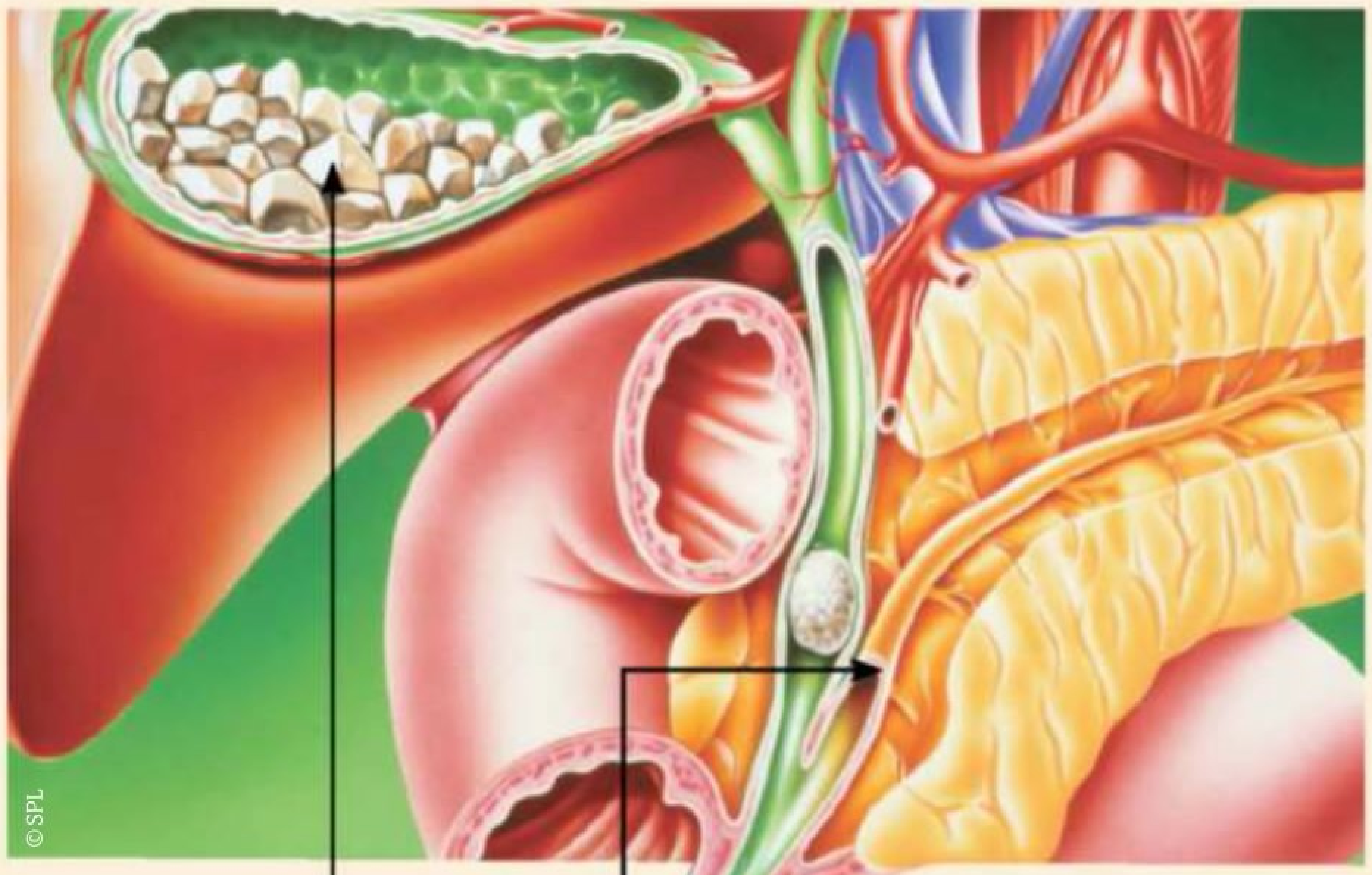
How do gallstones form?

What are these mineral deposits usually found in the gallbladder?

The gallbladder is a small, pear-shaped organ in which bile produced by the liver is stored. Over time the stored bile (composed of water, cholesterol, fats and natural salty detergents) becomes increasingly concentrated in order to better break down and absorb fats during digestion.

Gallstones, or cholelithiases, are the tiny deposits of salts and cholesterol that can form if there's a chemical imbalance in the gallbladder, often due to an excess of cholesterol in the bile. The 'stones' range in scale from tiny granular crystals to the size of a golf ball. Though they're usually formed in the gallbladder – and small stones cause no pain whatsoever – if a large gallstone becomes stuck in one of the many bile ducts that connect the gallbladder and the duodenum (start of the small intestine) a patient can experience great discomfort. If a gallstone blocks the flow of digestive enzymes produced in the pancreas, a condition called pancreatitis can develop, which can cause acute pain.

Ultrasound scans are able to detect gallstones and, if necessary, the gallbladder can be removed. Shockwave treatment can also be used to shatter stones, which can then be passed naturally.



© SPL

Gallstones
If there's an imbalance of chemicals in the bile, deposits of salt and cholesterol can form.

Bile duct
Although usually harmless, if a gallstone happens to get stuck in a bile duct, it can lead to intense pain and conditions such as jaundice.

Duodenum
Small stones can easily pass through the bile duct into the duodenum, where bile is usually introduced to aid digestion in the small intestine.

How important is our tongue?

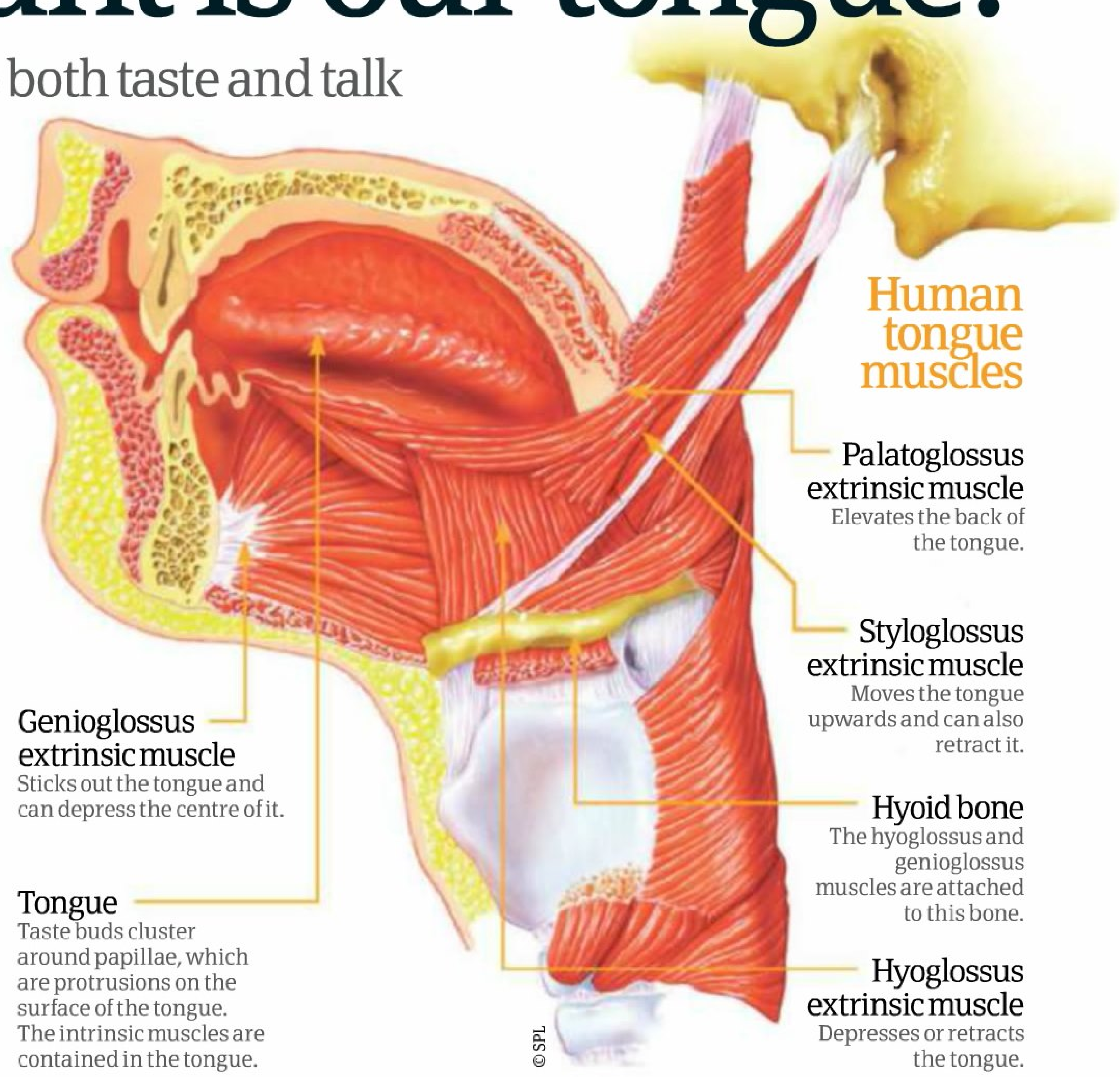
A versatile organ that allows you to both taste and talk

On our tongues, we have up to 10,000 taste buds that can distinguish between sweet, sour, bitter, salty and savoury flavours. As food is dissolved by our saliva, it meets taste receptor cells inside the taste buds that, when stimulated, send signals to the cerebral cortex. Receptors in the tongue also respond to other stimuli like pain, temperature and pressure.

The tongue consists of eight muscles: four of them are extrinsic muscles that are anchored to bone and change the position of the tongue, and four are intrinsic muscles that are not anchored to bone and change the shape of the organ.

Besides guiding food as we chew and swallow it, these muscles also give us the ability to speak. In combination with the mouth, jaws and cheeks the tongue moves to articulate sounds that emanate from the vocal folds of the larynx.

Tongues are not only integral to taste but also play a big role in speech



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Human tongue muscles

Palatoglossus extrinsic muscle
Elevates the back of the tongue.

Styloglossus extrinsic muscle
Moves the tongue upwards and can also retract it.

Hyoid bone
The hyoglossus and genioglossus muscles are attached to this bone.

Hyoglossus extrinsic muscle
Depresses or retracts the tongue.

Genioglossus extrinsic muscle
Sticks out the tongue and can depress the centre of it.

Tongue
Taste buds cluster around papillae, which are protrusions on the surface of the tongue. The intrinsic muscles are contained in the tongue.

What's the retina made of?

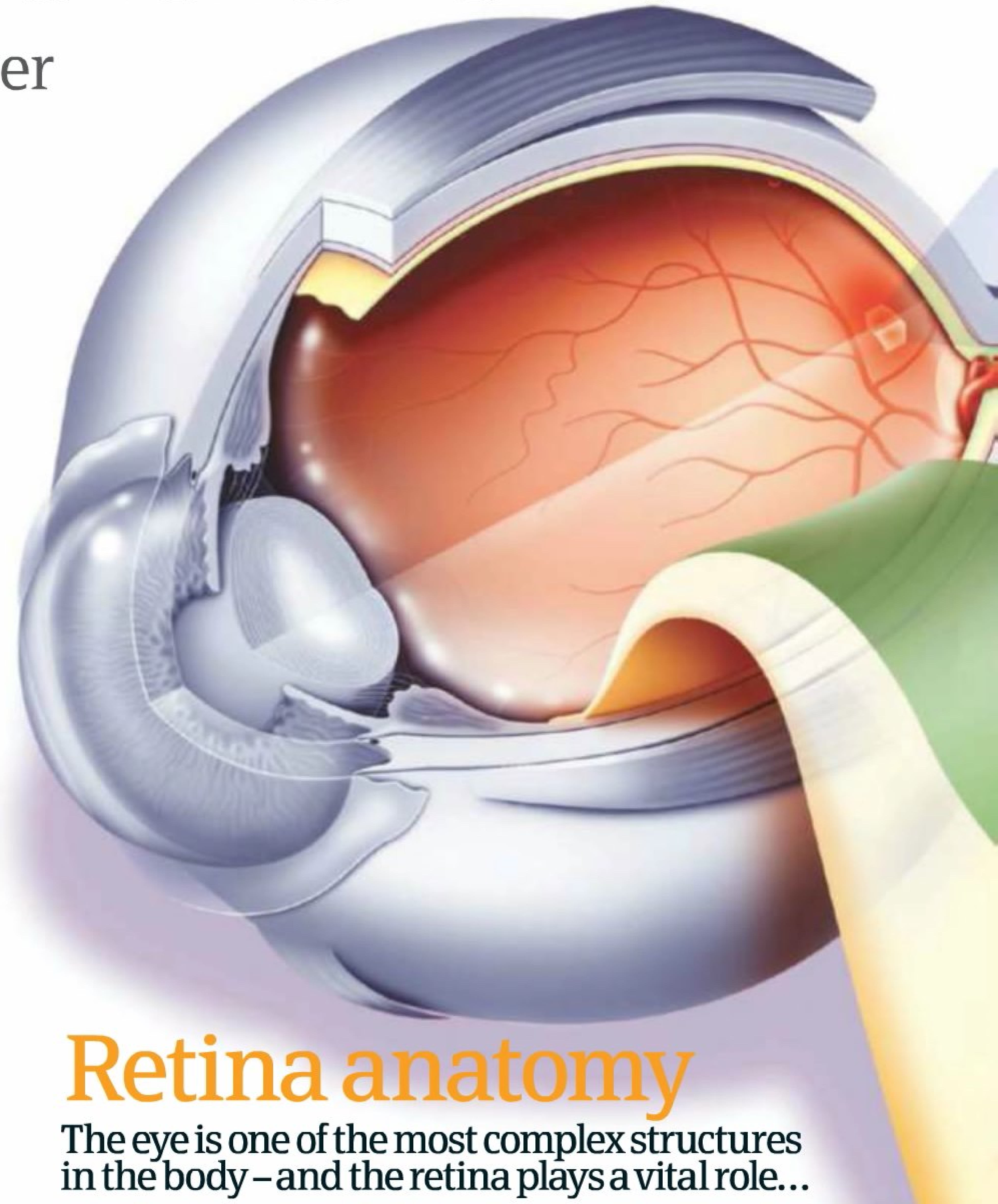
How does this photosensitive layer enable us to see pictures?

The retina is a special type of light-sensitive tissue located in the interior of the eye that's so analogous to brain tissue, it's considered a part of the central nervous system. If you consider our eyes to be cameras, then the retina is the film. However, the retina does much more than just send a 'picture' to the brain – it actually has to compress the image so that it can be conveyed via the optic nerve, because the photoreceptors in the retina can take in more information than the optic nerve can convey.

Although it looks like a single layer, the retina is actually very complex and comprises ten layers of nerve cells, all of which are connected by synapses. Within each of these layers are several different types of cells: the photoreceptors called rods and cones, photosensitive ganglion cells, bipolar cells and other cells that assist with regulating light input as well as processing and transmitting images. Rods and cones each have their own function. Rods are more sensitive to light and are responsible for night vision and peripheral vision; each one can respond to a single photon, or particle, of light. Cones, on the other hand, work in bright light and are responsible for seeing colour, fine detail and rapid movements.

Until the Nineties, it was thought that only rods and cones were involved in sight. Then researchers discovered a much rarer type of cell called photosensitive ganglion cells. These cells help regulate pupil size and the light/dark cycle, or circadian rhythms, that we function by.

Light reaches the rods and cones by first passing through transparent layers of nerve cells. When it reaches these photoreceptors, the light causes chemical changes in both the rods and cones. The raw data is then sent back through the layers of nerve cells, which process and encode the image before sending it via the optic nerve to the brain.



Retina anatomy

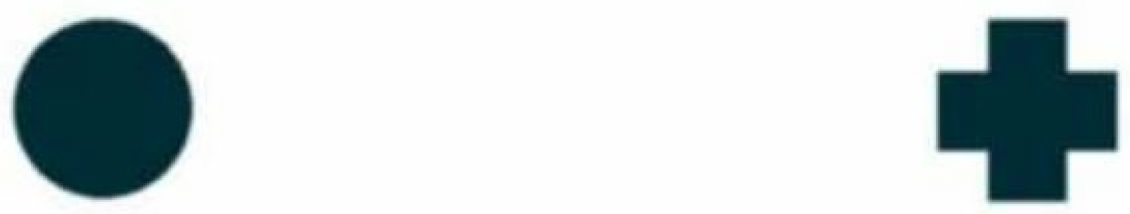
The eye is one of the most complex structures in the body – and the retina plays a vital role…

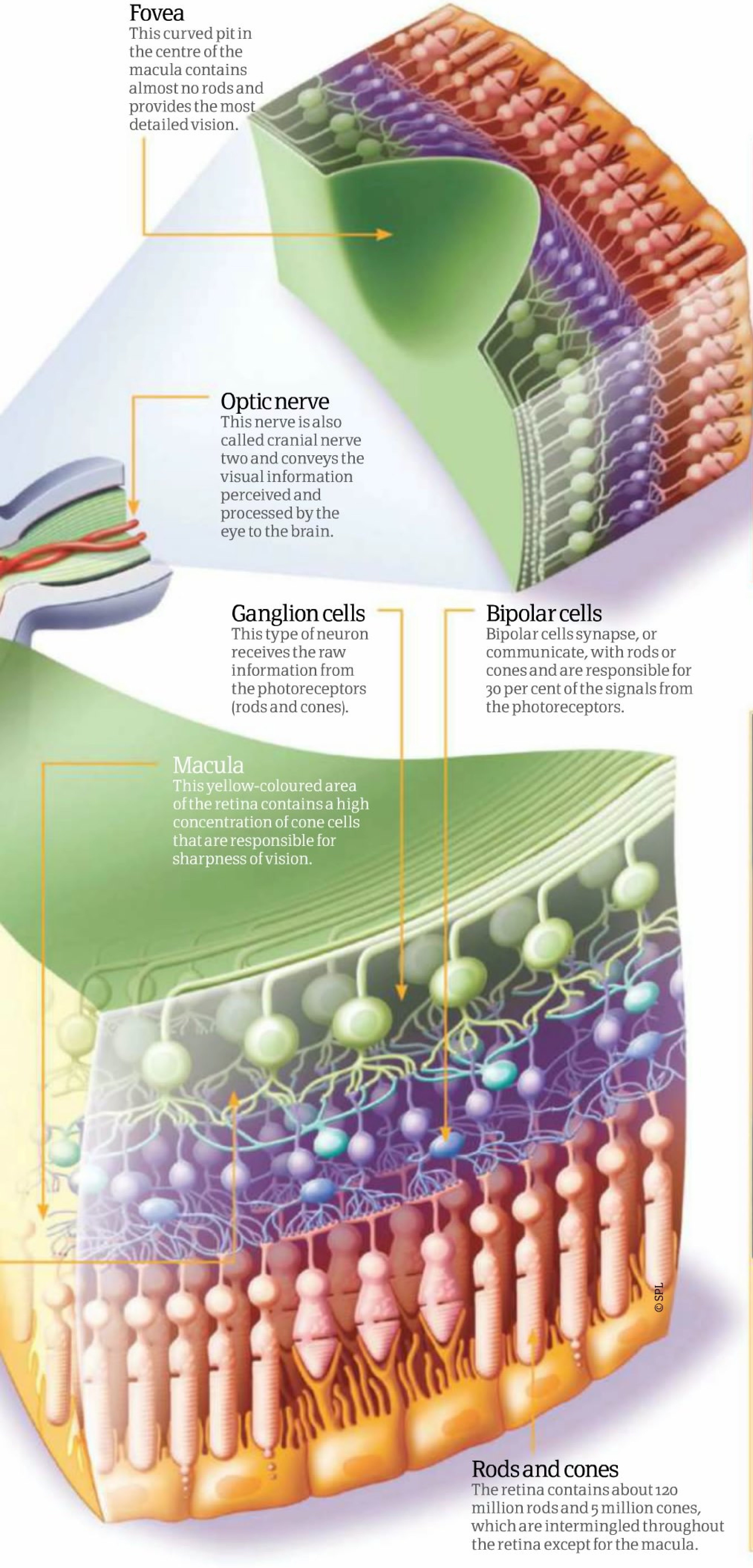
Amacrine cells
These are responsible for 70 per cent of the photoreceptors' input and they regulate the bipolar cells.

Blind spot

We all have a blind spot, or scotoma – a place on the retina where there are no photoreceptive cells to perceive light. Known as the optic disc, this area is where the optic nerve passes through the retina on the way to the brain. Although the blind spot is sizeable, we don't notice it. That's because the blind spot in each eye is in a different place, so the other eye 'fills in' the blanks. To the right we have included a 'blind spot test'. When you close your left eye and focus on the circle, then slowly get closer to the page, the plus sign will vanish!

THE BLIND SPOT TEST





Fovea
This curved pit in the centre of the macula contains almost no rods and provides the most detailed vision.

Optic nerve
This nerve is also called cranial nerve two and conveys the visual information perceived and processed by the eye to the brain.

Ganglion cells
This type of neuron receives the raw information from the photoreceptors (rods and cones).

Bipolar cells
Bipolar cells synapse, or communicate, with rods or cones and are responsible for 30 per cent of the signals from the photoreceptors.

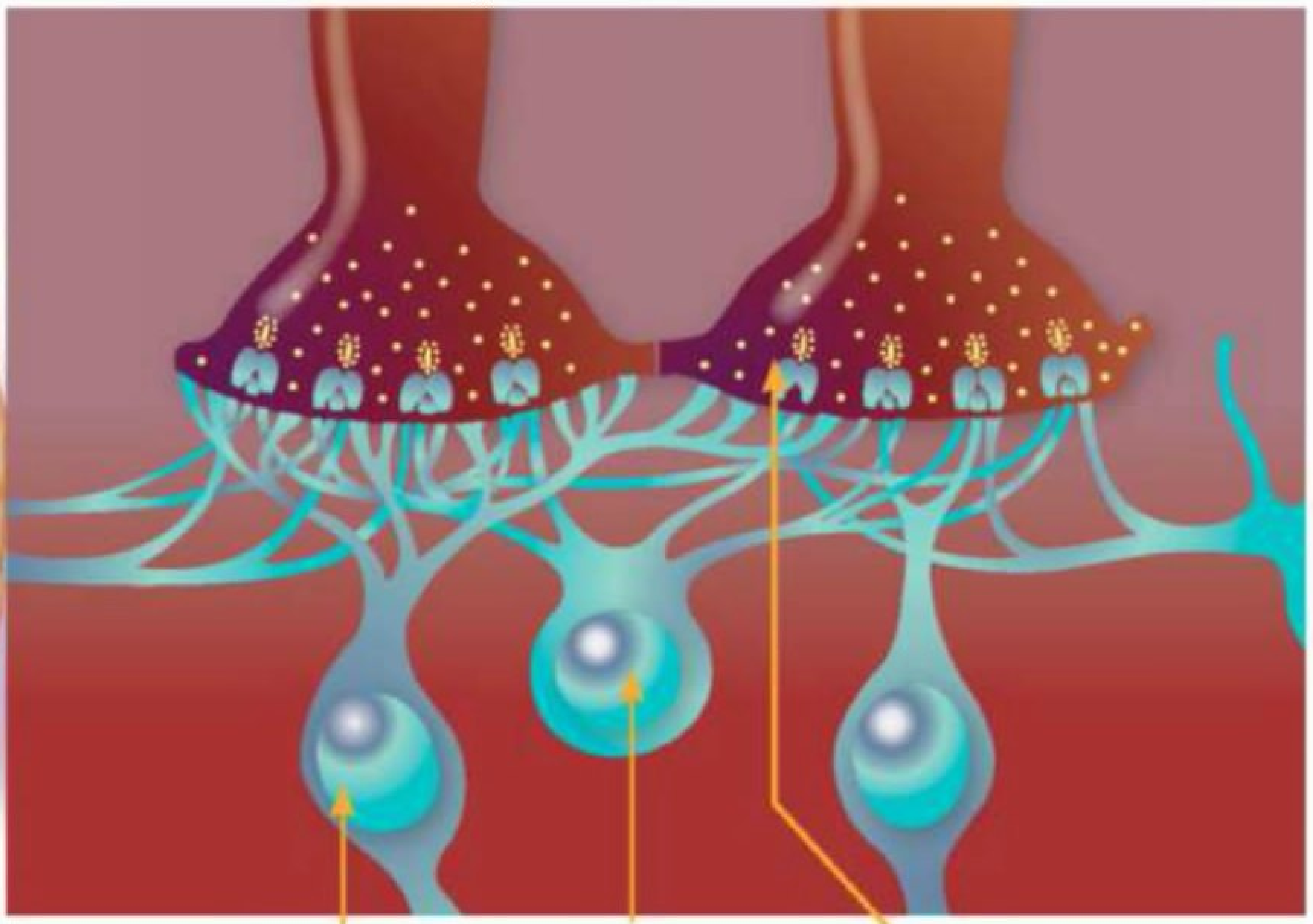
Macula
This yellow-coloured area of the retina contains a high concentration of cone cells that are responsible for sharpness of vision.

Rods and cones
The retina contains about 120 million rods and 5 million cones, which are intermingled throughout the retina except for the macula.

© SPL

Synapses

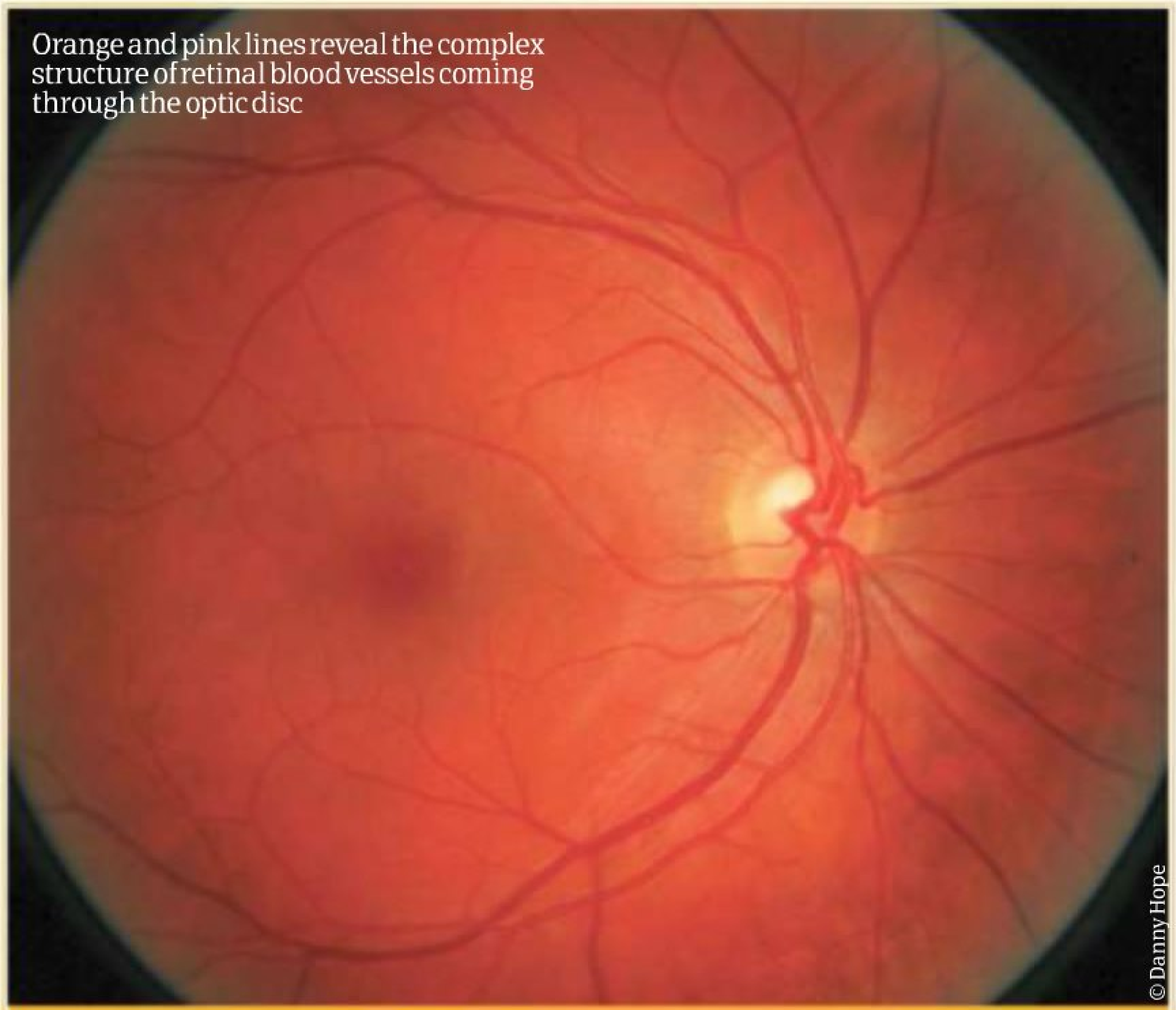
Neurons combine data from rod and cone cells into messages that travel to the brain



Bipolar cells
Each bipolar cell corresponds to a specific cone or rod cell.

Horizontal cells
These neurons interconnect different types of photoreceptors and also regulate their function.

Photoreceptors
Rods and cones each transmit their own input during the vision process.



Orange and pink lines reveal the complex structure of retinal blood vessels coming through the optic disc

© Danny Hope

Retinal scan

Iris scanning is the more common form of biometrics when it comes to eyes, but did you know that our retinas also have identifying characteristics? It all comes down to the complex network of blood vessels in the retina; even twins' retinas are different. When you look into a retinal scanner, a low-energy beam of infrared light is reflected by the capillaries. The resulting pattern is then stored as code within a database. Retinal scanners are fast and reliable, but the downside is that the scanners are expensive and the pattern can change over time with certain diseases or other eye problems.

How does an embryo grow?

Discover how a fertilised egg transforms into an embryo and eventually a new human being

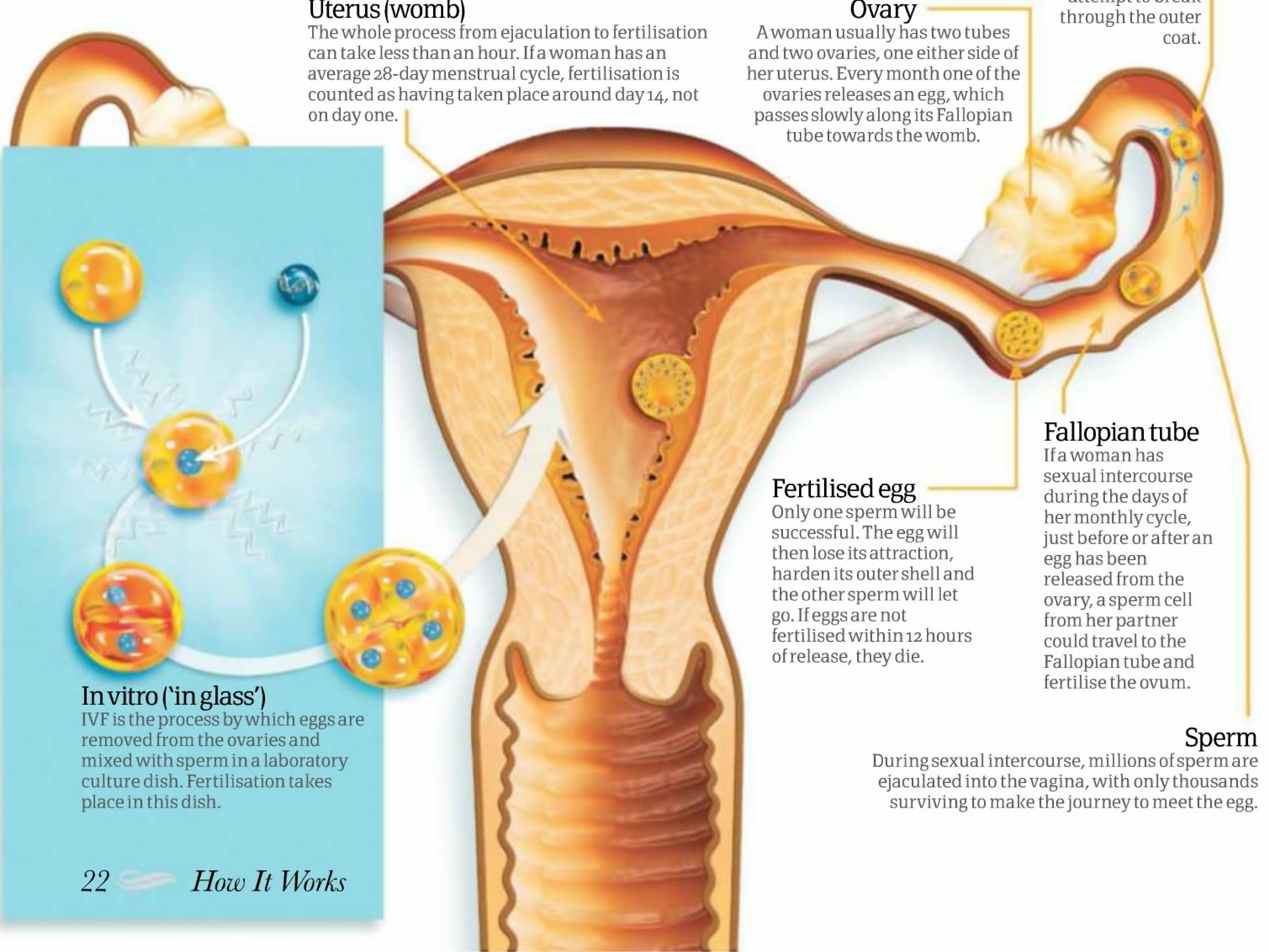
After fertilisation, the single-celled zygote splits into two, then the two cells double to four, four to eight and so on. The journey along the Fallopian tube is quite slow, while growth continues. On its way, the zygote divides to make a clump of 32 cells, known as the morula stage. If the early embryo splits into two clumps before this, it may develop into identical twins. Every cell in the morula could still become part of the growing embryo.

By the time the womb cavity is reached, the cell cluster becomes hollow and filled with fluid; it is now referred to as the blastocyst. A blastocyst is an embryo that has developed to the stage where it has two different cell types: the surface cells, or outer coat, will become – among other things – the placenta that nourishes the baby. The inner cells will become the foetus itself. On contact, the blastocyst burrows into the uterine wall for nourishment; this process is known as implantation.

The embryonic stage begins in the fifth week. From weeks five to eight, development is rapid. Major body organs and systems will begin to emerge. At this time, the first bone cells will also appear. By the end of the eighth week, the embryo is known as a foetus and looks like a mini human.

Fertilisation and IVF explained

Fertilisation occurs when the sperm and egg unite in one of the female's Fallopian tubes. The fertilised egg, known as a single-celled zygote, then travels to the uterus, where it implants into the uterine lining. In vitro fertilisation (IVF) is a form of assisted reproductive technology, where the sperm nucleus is combined with an egg cell in a lab. The resultant embryo is manually introduced to the uterus, where it develops in the same way as a natural conception.



Uterus (womb)
The whole process from ejaculation to fertilisation can take less than an hour. If a woman has an average 28-day menstrual cycle, fertilisation is counted as having taken place around day 14, not on day one.

Ovary
A woman usually has two tubes and two ovaries, one either side of her uterus. Every month one of the ovaries releases an egg, which passes slowly along its Fallopian tube towards the womb.

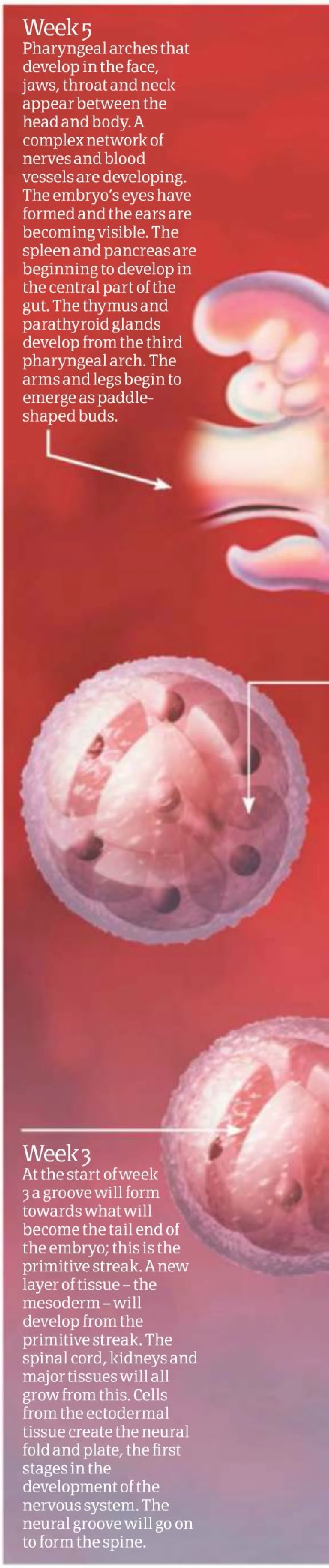
Ovulated egg
The sperm cells are chemically attracted to the egg and attach themselves in an attempt to break through the outer coat.

Fertilised egg
Only one sperm will be successful. The egg will then lose its attraction, harden its outer shell and the other sperm will let go. If eggs are not fertilised within 12 hours of release, they die.

Fallopian tube
If a woman has sexual intercourse during the days of her monthly cycle, just before or after an egg has been released from the ovary, a sperm cell from her partner could travel to the Fallopian tube and fertilise the ovum.

Sperm
During sexual intercourse, millions of sperm are ejaculated into the vagina, with only thousands surviving to make the journey to meet the egg.

In vitro ('in glass')
IVF is the process by which eggs are removed from the ovaries and mixed with sperm in a laboratory culture dish. Fertilisation takes place in this dish.

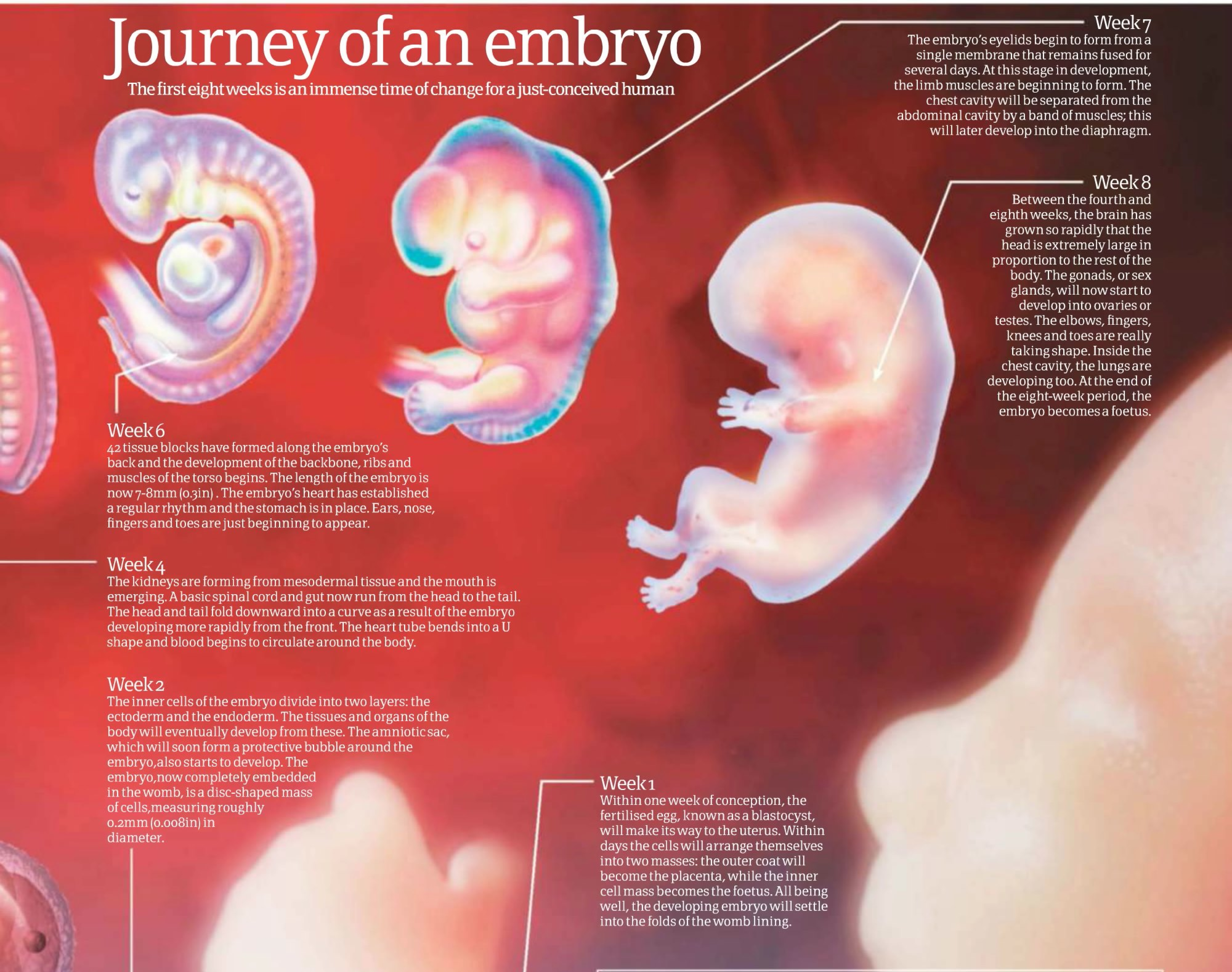


Week 5
Pharyngeal arches that develop in the face, jaws, throat and neck appear between the head and body. A complex network of nerves and blood vessels are developing. The embryo's eyes have formed and the ears are becoming visible. The spleen and pancreas are beginning to develop in the central part of the gut. The thymus and parathyroid glands develop from the third pharyngeal arch. The arms and legs begin to emerge as paddle-shaped buds.

Week 3
At the start of week 3 a groove will form towards what will become the tail end of the embryo; this is the primitive streak. A new layer of tissue – the mesoderm – will develop from the primitive streak. The spinal cord, kidneys and major tissues will all grow from this. Cells from the ectodermal tissue create the neural fold and plate, the first stages in the development of the nervous system. The neural groove will go on to form the spine.

Journey of an embryo

The first eight weeks is an immense time of change for a just-conceived human



Week 7
The embryo's eyelids begin to form from a single membrane that remains fused for several days. At this stage in development, the limb muscles are beginning to form. The chest cavity will be separated from the abdominal cavity by a band of muscles; this will later develop into the diaphragm.

Week 8
Between the fourth and eighth weeks, the brain has grown so rapidly that the head is extremely large in proportion to the rest of the body. The gonads, or sex glands, will now start to develop into ovaries or testes. The elbows, fingers, knees and toes are really taking shape. Inside the chest cavity, the lungs are developing too. At the end of the eight-week period, the embryo becomes a foetus.

Week 6
42 tissue blocks have formed along the embryo's back and the development of the backbone, ribs and muscles of the torso begins. The length of the embryo is now 7-8mm (0.3in). The embryo's heart has established a regular rhythm and the stomach is in place. Ears, nose, fingers and toes are just beginning to appear.

Week 4
The kidneys are forming from mesodermal tissue and the mouth is emerging. A basic spinal cord and gut now run from the head to the tail. The head and tail fold downward into a curve as a result of the embryo developing more rapidly from the front. The heart tube bends into a U shape and blood begins to circulate around the body.

Week 2
The inner cells of the embryo divide into two layers: the ectoderm and the endoderm. The tissues and organs of the body will eventually develop from these. The amniotic sac, which will soon form a protective bubble around the embryo, also starts to develop. The embryo, now completely embedded in the womb, is a disc-shaped mass of cells, measuring roughly 0.2mm (0.008in) in diameter.

Week 1
Within one week of conception, the fertilised egg, known as a blastocyst, will make its way to the uterus. Within days the cells will arrange themselves into two masses: the outer coat will become the placenta, while the inner cell mass becomes the foetus. All being well, the developing embryo will settle into the folds of the womb lining.

What is amniotic fluid?

The amniotic sac is a bag of fluid in the uterus, where the unborn baby develops. It's filled with a colourless fluid – mainly made of water – that helps to cushion the foetus and provides fluids which enable the baby to breathe and swallow. The fluid also guards against infection to either the foetus or the uterus. Amniotic fluid plays a vital role in the development of internal organs, such as the lungs and kidneys; it also maintains a constant temperature. The amniotic sac starts to form and fill with fluid within days of conception.

The body of this foetus is really taking shape, safe within the amniotic sac

3x © SPL

Why do people have different skin colour?

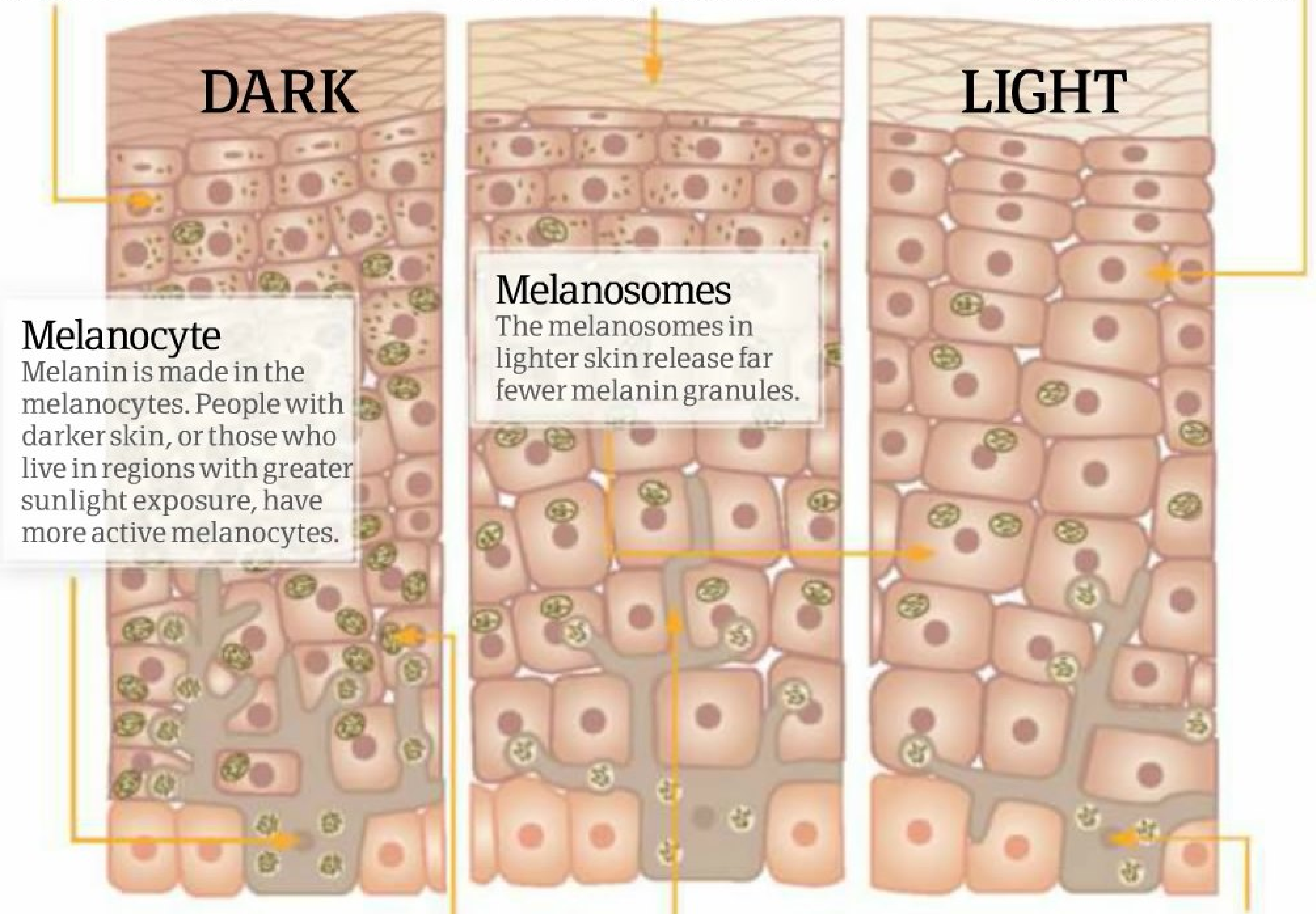
What is melanin and how does it affect the tone of our skin?

The light-absorbing pigment melanin is a chemical substance that gives your skin its natural colouring. Skin can vary from very dark brown to almost completely white due to a combination of your genes and inherited traits and the amount of sunlight to which you are exposed.

Skin colour differs from person to person depending on the concentration of melanin present in their skin and its distribution throughout the skin's layers. Basically, those with less melanin have lighter skin, while those with more of the pigment have darker skin. Melanin is produced by specialised skin cells called melanocytes in the lower layers of the epidermis and is contained inside a melanosome by a very thin membrane.

Exposure to sunlight stimulates the production of melanin granules. The melanosomes containing the melanin then move out towards the skin's protective keratinocyte cells along branch cells called dendrites. Melanin is then stored in the nuclei of the keratinocytes where it acts as a natural protector against the effects of the Sun's ultraviolet rays. Keratinocytes make up the bulk of the outer layers of the skin and form the barrier between the body and the outside world. They take up melanin which can absorb cancer-causing UV radiation so it doesn't get into the body's internal tissues.

Melanin and skin colour



Keratinocytes
These protective cells are produced in the lower layers of the epidermis. They take up the melanosomes produced by the melanocytes.

Surface
Basal skin cells manufactured in the lower layers of the epidermis grow through the skin to the surface, where they are eventually sloughed away.

Keratinocytes
The keratinocytes of lighter-skinned people take up fewer melanosomes.

Melanocyte
Melanin is made in the melanocytes. People with darker skin, or those who live in regions with greater sunlight exposure, have more active melanocytes.

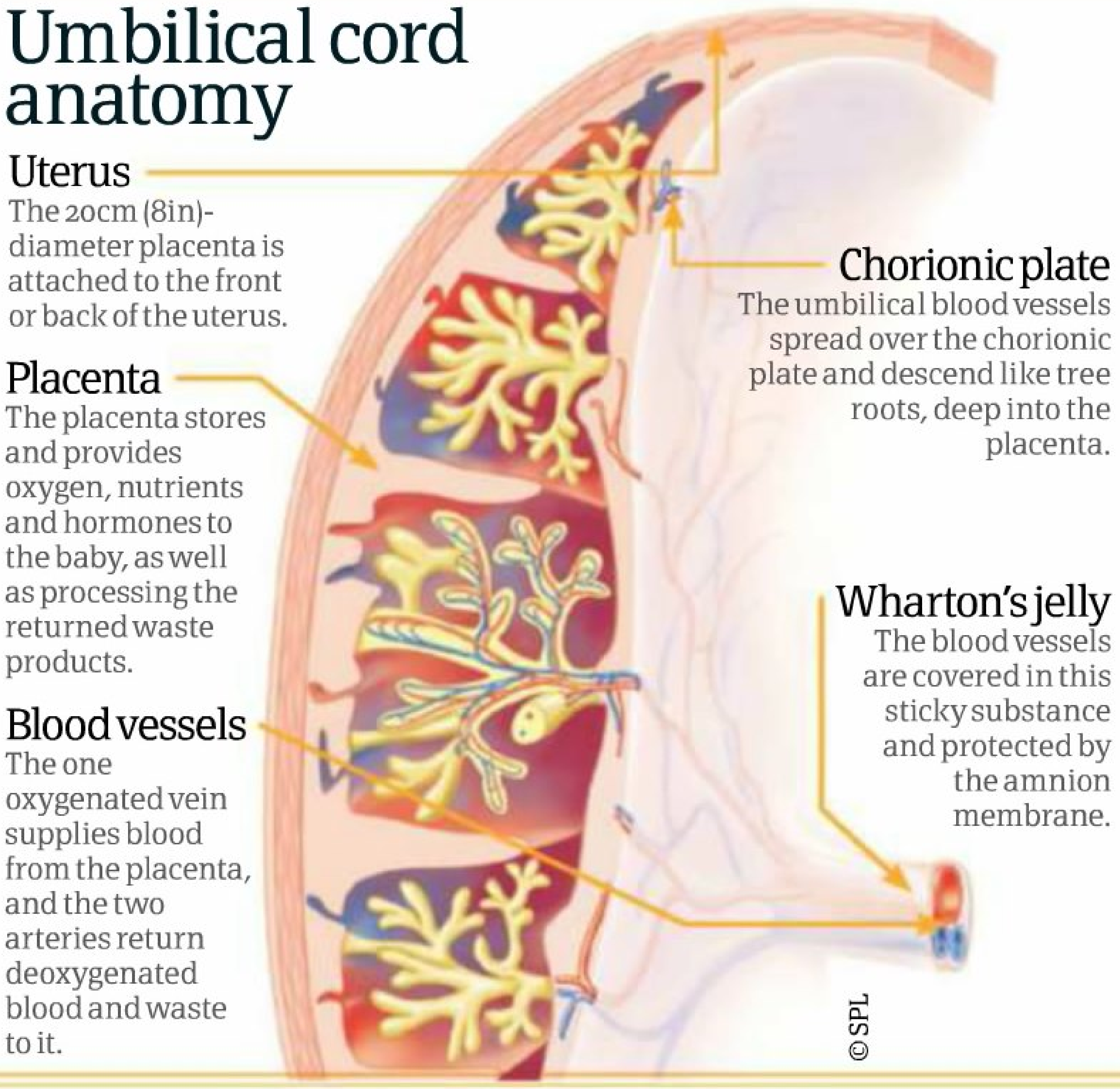
Melanosomes
The melanosomes in lighter skin release far fewer melanin granules.

Melanosomes
These packets of melanin release melanin granules into the keratinocytes.

Dendrite
These branching cells pass melanin to keratinocytes.

Melanocyte
Those with lighter skin have fewer dendrites in their lower layers and their melanocytes are also less active.

Umbilical cord anatomy



Uterus
The 20cm (8in)-diameter placenta is attached to the front or back of the uterus.

Placenta
The placenta stores and provides oxygen, nutrients and hormones to the baby, as well as processing the returned waste products.

Blood vessels
The one oxygenated vein supplies blood from the placenta, and the two arteries return deoxygenated blood and waste to it.

Chorionic plate
The umbilical blood vessels spread over the chorionic plate and descend like tree roots, deep into the placenta.

Wharton's jelly
The blood vessels are covered in this sticky substance and protected by the amnion membrane.

© SPL

What does the umbilical cord actually do?

The essential link between mother and baby explained

The umbilical cord runs from the centre of the mother's placenta to an opening in the baby's stomach. It consists of an umbilical vein and two arteries. The vein supplies the baby with nutrients and oxygenated blood from the placenta, while the two arteries return carbon dioxide and other waste products and deoxygenated blood back to the placenta. They are coated with protective Wharton's jelly, and sheathed with a transparent membrane called amnion.

The maternal blood supply divides inside the baby to distribute blood to the liver and heart. This oxygenated blood circulates rapidly to renew the baby's oxygen levels, and this role is taken over by the lungs after birth.

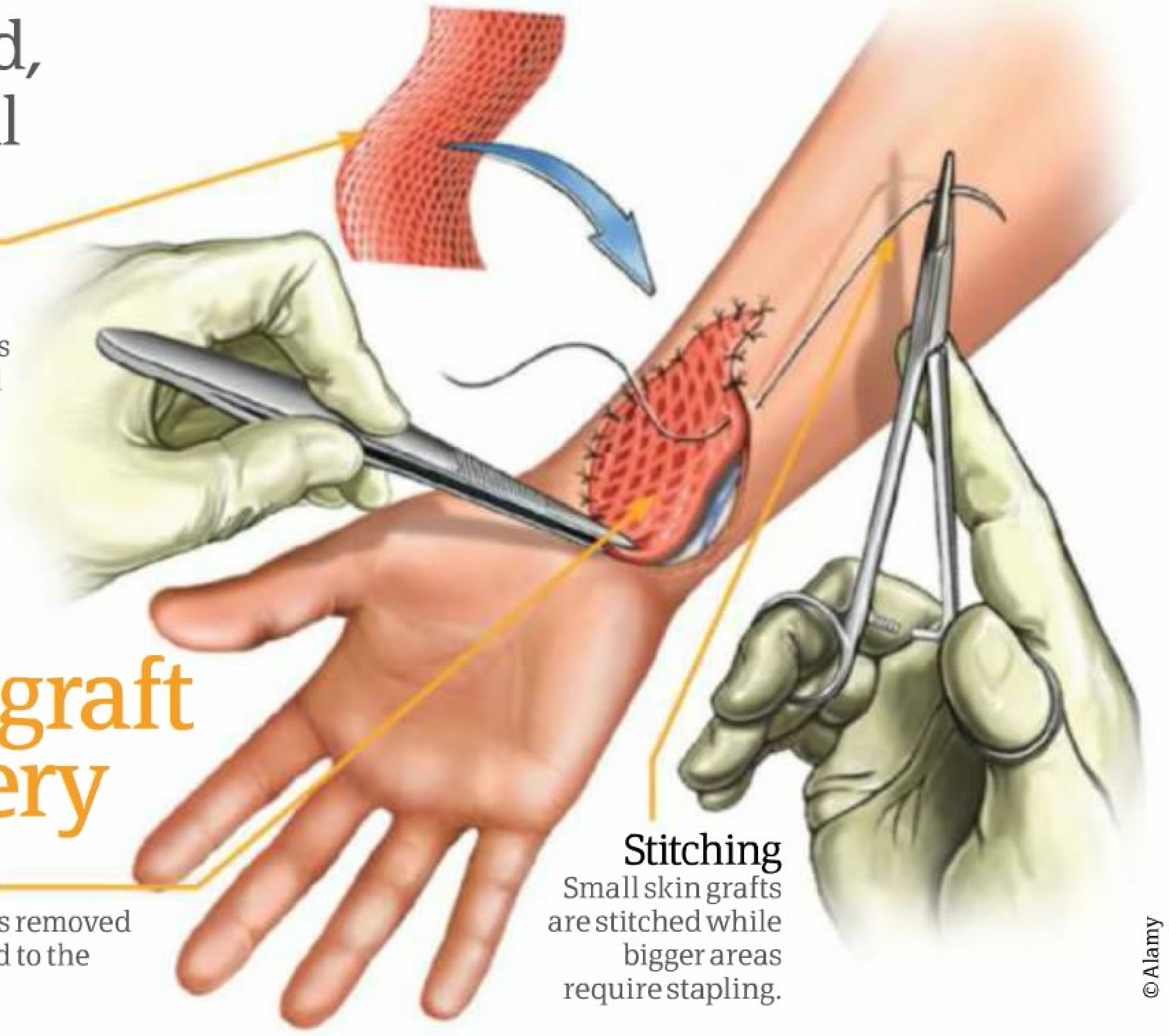
How do skin grafts work?

When our body's largest organ is damaged, sometimes it needs a helping hand to heal

Skin grafting is a medical procedure where a portion of skin is removed and stitched onto another part of the body. There are many cosmetic and medical reasons why this might be necessary: serious burns, surgery, tattoo removal and some medical conditions (skin cancer or diabetes, for example) might all necessitate skin grafting. Autografts are skin grafts taken from the patient's own body, usually the buttocks, neck or back of the arm. Depending on the size of the area that it's removed from, it's then stitched or stapled closed again and the new skin applied to the injured area. Allografts and xenografts, meanwhile – taken from other humans and animals, respectively – are temporary grafts.

But perhaps most interesting is the artificial 'skin' called Integra, made of animal collagen that gives the damaged part an organic scaffolding for new skin to grow into. This is usually used in cases of extreme burns where there isn't enough healthy skin for an autograft.

Skin graft surgery



Gauze
A sterile gauze is applied while the skin attaches and a new blood supply establishes.

Donor skin
The donor skin is removed and then applied to the injured area.

Stitching
Small skin grafts are stitched while bigger areas require stapling.

© Alamy

Why do blisters form?

Why do burns cause bubbles to develop below the surface of the skin?

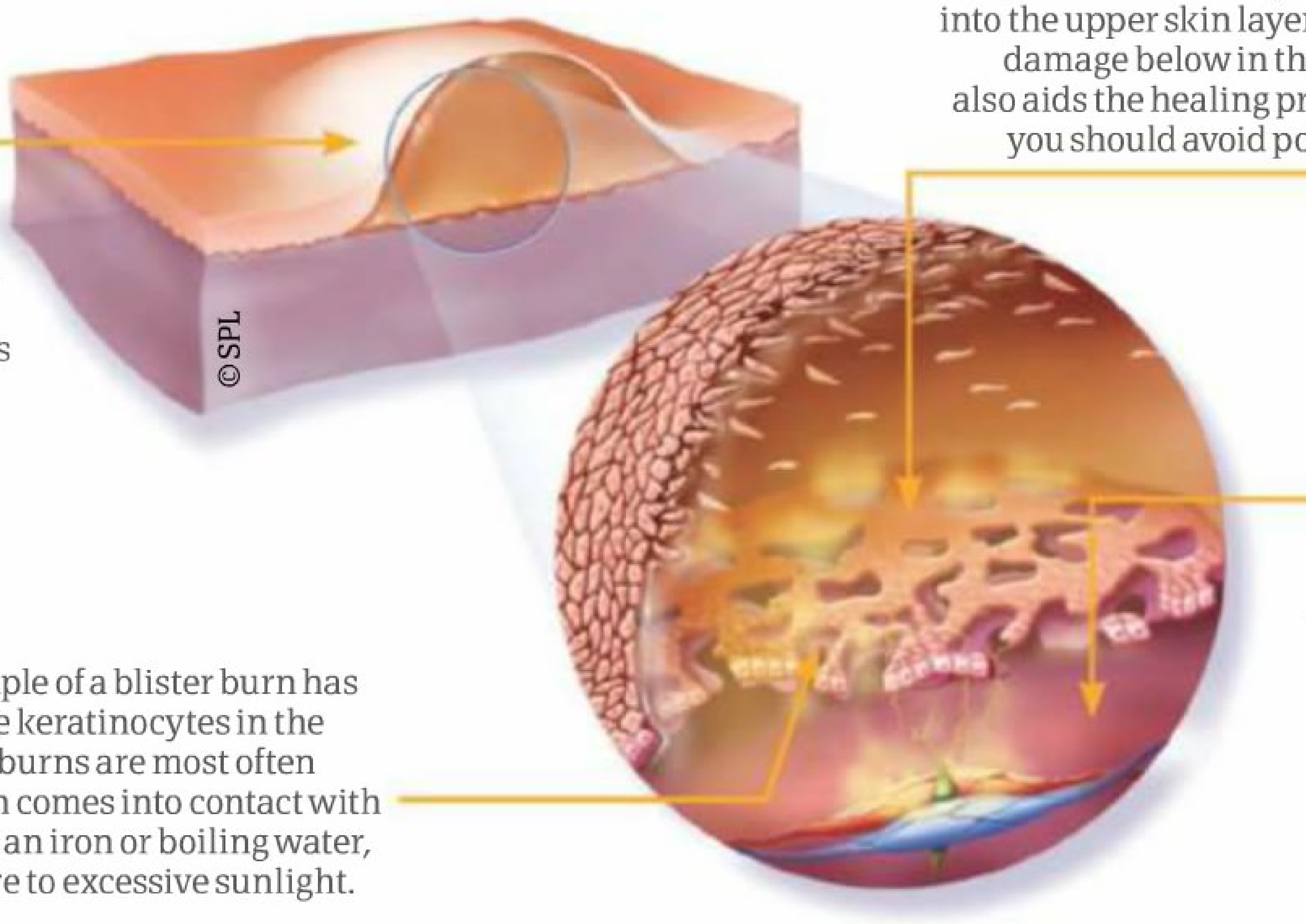
Blisters shouldn't be burst as they are the body's way of protecting deeper skin layers

Though our skin is an amazing protector against the elements, it can become damaged by such factors as heat, cold, friction, chemicals, light, electricity and radiation, all of which 'burn' the skin. A blister is the resulting injury that develops in the upper layers of the skin as a result of such burns.

The most common example of a blister, which we've no doubt all experienced at some time, is due to the repeated friction caused by the material of a pair of shoes rubbing against, and irritating, the skin. The resulting water blister is a kind of plasma-filled bubble that appears just below the top layers of your skin. The plasma, or serum – which is a component of your blood – is released by the damaged tissue cells and fills the spaces between the layers of skin in order to cushion the underlying skin that is being rubbed and protect it from further damage. As more and more serum pours into the space, the skin begins to inflate under the pressure, forming a small balloon full of the serous liquid. Given time to heal, the skin will reabsorb the plasma after about 24 hours.

Similarly, a blood blister is a variation of the same injury where the skin has been forcefully pinched or crushed but not pierced, causing small blood vessels to rupture, leaking blood into the skin. All blisters can be tender but should never be popped in order to drain the fluid as this leaves the underlying skin unprotected and also invites infection into the wound.

Blister caused by second-degree burns



© SPL

Skin
When any type of burn is experienced, the overlying skin expands as it receives the protective plasma/serum.

Damage
This particular example of a blister burn has caused damage to the keratinocytes in the skin. Second-degree burns are most often caused when the skin comes into contact with a hot surface, such as an iron or boiling water, or even after exposure to excessive sunlight.

Plasma
Serum is released by the damaged tissues into the upper skin layers to prevent further damage below in the epidermal layer. It also aids the healing process, which is why you should avoid popping your blisters.

Fluid reabsorbed
After a day or so the serum will be absorbed back into the body and the raised skin layers will dry out and flake off in their own time.

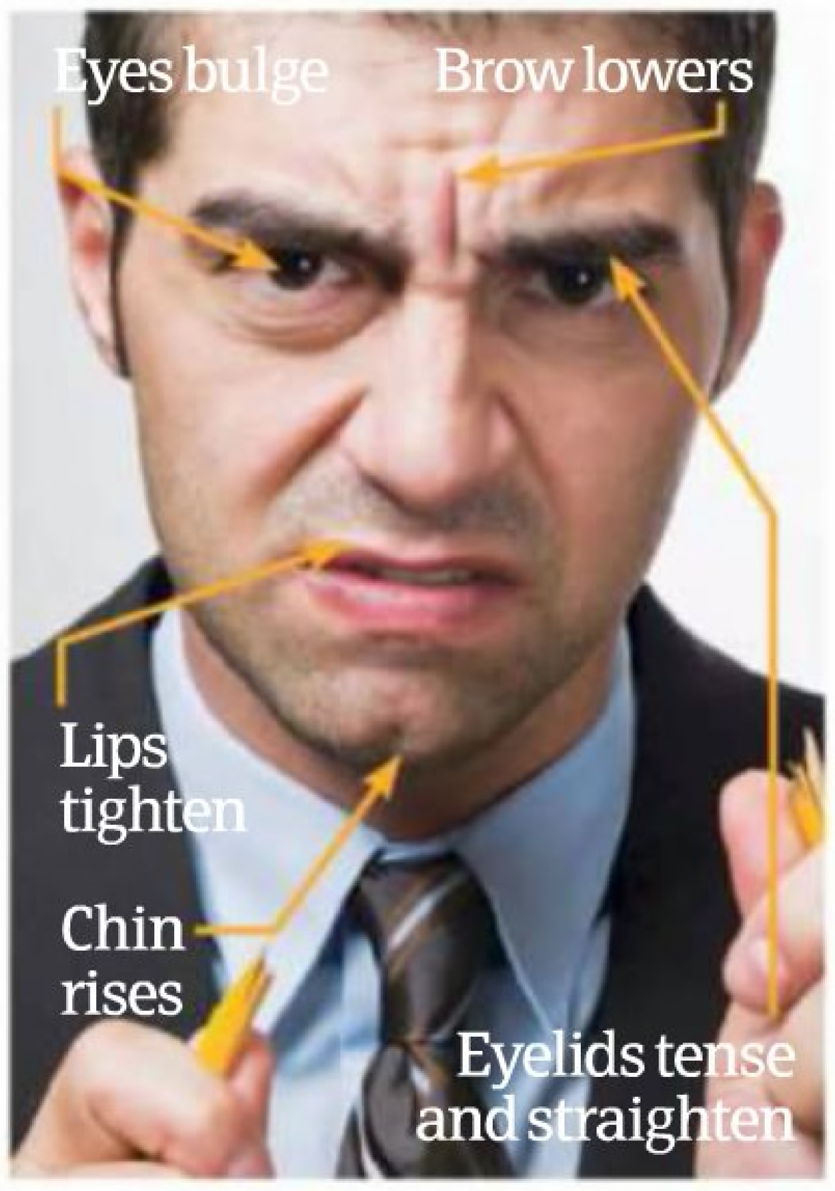
What happens when you get angry?

Learn what happens when someone loses it…

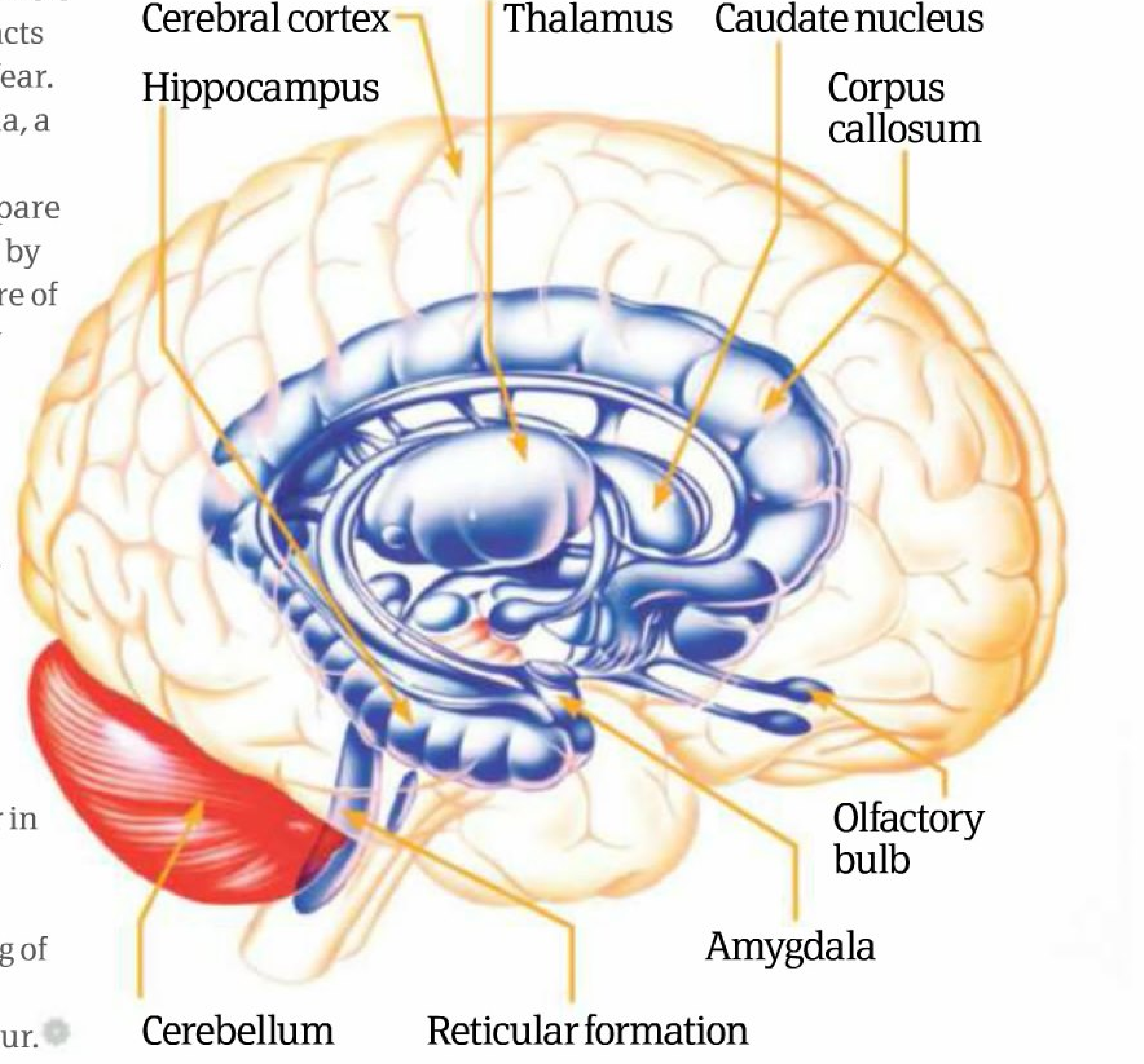
Anger is one of the six universal emotions experienced by humans. Our emotions are the largely unconscious physical responses we have to stimuli. While we use the cerebral cortex in the brain to think logically and make judgements, anger is controlled by the limbic system, a group of structures buried lower down in the primitive regions of the brain. A sophisticated network of nerve pathways controls instinct and governs such emotions as fear and rage. We get angry to protect ourselves from danger if something threatens us, our belongings or anyone that we care about.

Within the limbic system is the amygdala, a structure in which we store our emotional memories. Anger is a primitive form of self-preservation and it's the limbic system that invokes our natural instincts such as the fight-or-flight response to fear. When a stimulus triggers the amygdala, a flood of hormones is produced automatically to warn the body to prepare for action. Because anger is controlled by the emotional centre of the brain, an angry person can temporarily lose control of their actions as well as the things they say. This is why we often refer to someone as 'losing it' when they get really mad.

We exhibit anger in a variety of ways, including facial expressions, raising of the voice and more aggressive behaviour.



Exploring the limbic system



How do we laugh?

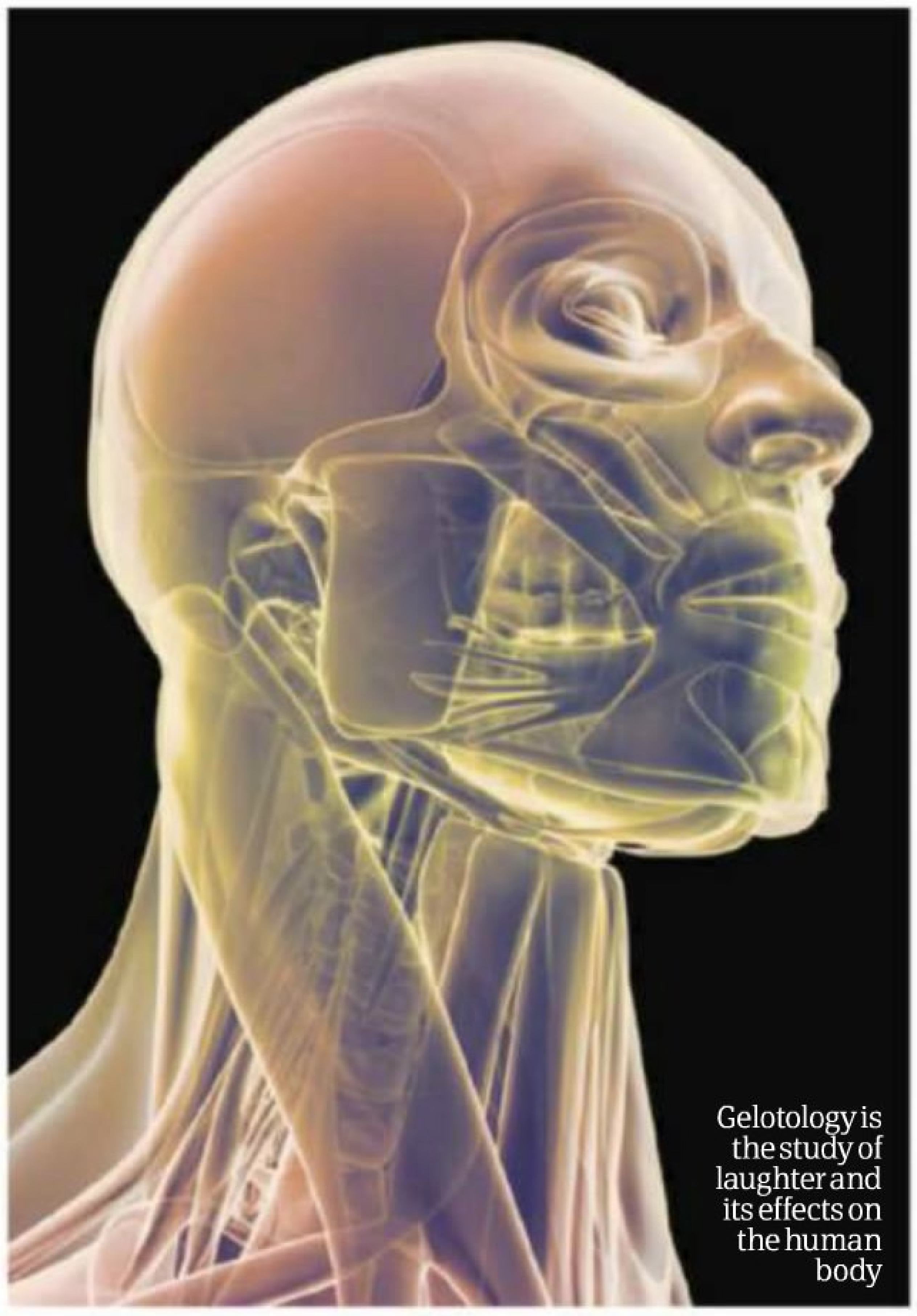
The muscles involved and why it's hard to fake

Laughing can sometimes be completely involuntary and involves a complex series of muscles, which is why it's so difficult to fake and also why an active effort is required to suppress laughter.

In the face, the zygomaticus major and minor anchor at the cheekbones and stretch down towards the jaw to pull the facial expression upward; on top of this, the zygomaticus major also pulls the upper lip upward and outward.

The sound of our laugh is produced by the same mechanisms used for coughing and speaking: namely, the lungs and the larynx. When we're breathing normally, air from the lungs passes through the open vocal cords in the larynx. When they close, air cannot pass, however when they're partially open, they generate some form of sound. Laughter is the result when we exhale while the vocal cords close, with the respiratory muscles periodically activating to produce the characteristic rhythmic sound of laughing.

The risorius muscle is used to smile, but affects a smaller portion of the face and is easier to control than the zygomatic muscles. As a result, the risorius is more often used to feign amusement, hence why fake laughter is easy to detect.



Gelotology is the study of laughter and its effects on the human body

© Alamy

What makes us sneeze?

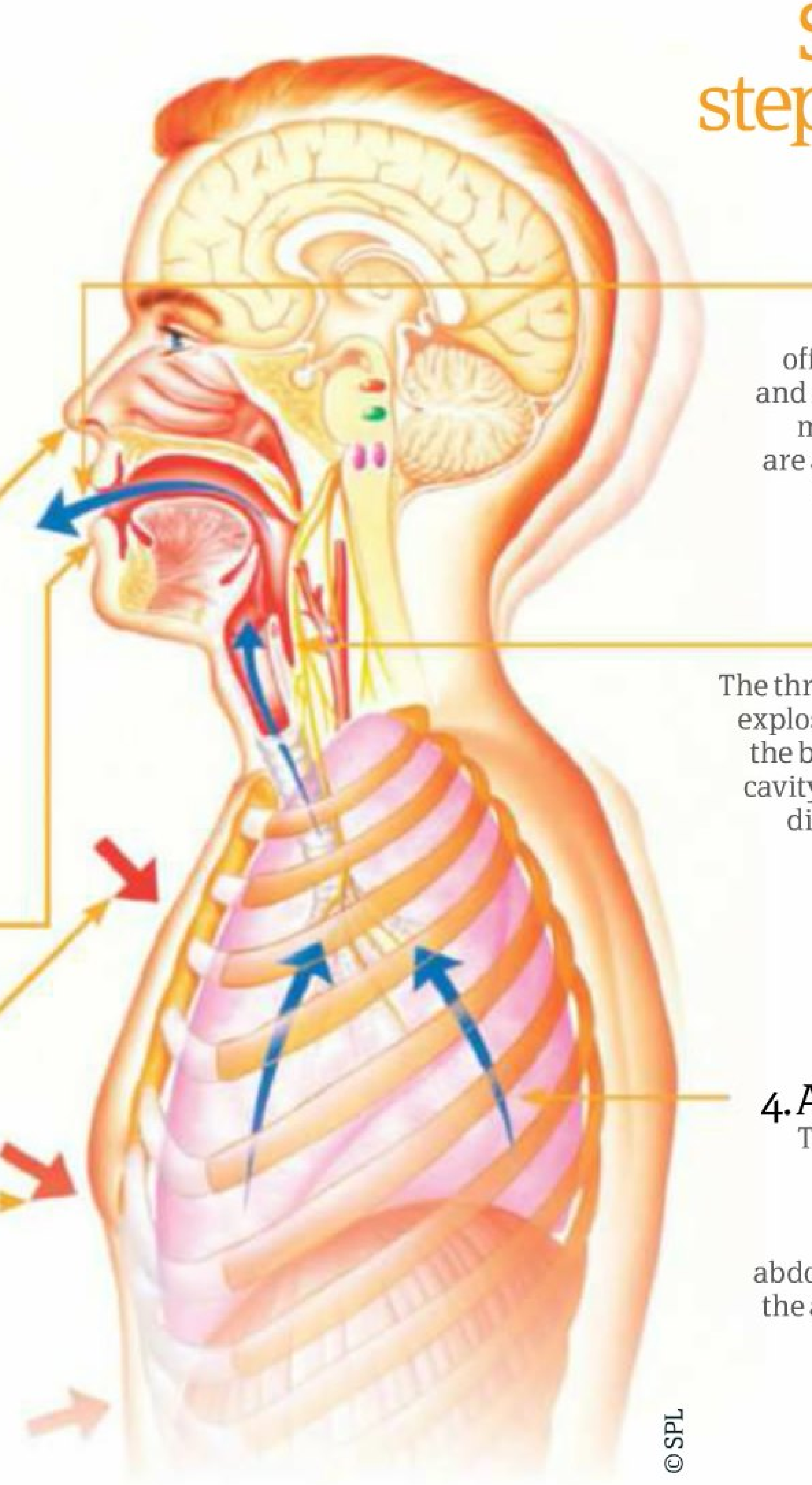
How does this automatic reflex expel unwanted irritants from the body?

When we breathe in, the inhaled air can contain dust, chemicals and other irritants that can be harmful to the body, particularly to organs in the respiratory system like the lungs. While the tiny hairs inside the nostrils (cilia) trap many of these particles, some will often get through. To help you out, your body reacts to try and forcibly expel the offending particles via the sneeze reflex arc.

There are a number of other reasons why we sneeze, including to clear the nasal passages when you have a cold, to expel allergens if you are allergic to something, and even bright sunlight can cause some people to sneeze.

When a stimuli is detected by the nerve endings in the nose, impulses are sent to the brain, which initiates a chain of physiological events that enable the body to rid itself of the unwelcome item.

Sneezing step-by-step



1. Irritation
Prior to irritation, the diaphragm muscles are relaxed. When an irritant enters the body, nerve endings in the lining of the nose signal to the brain.

2. Muscles contract
The brain tells the respiratory muscles – including throat, chest and diaphragm – to contract.

3. Intake of breath
Contraction of the diaphragm causes a sharp intake of breath.

4. Air pressure rises
The brain signals to the throat to close. This, combined with the contraction of the abdominal muscles, raises the air pressure inside the lungs.

5. Sneeze
The throat reopens suddenly, explosively forcing air out of the body, making the chest cavity contract sharply. The diaphragm relaxes once again.

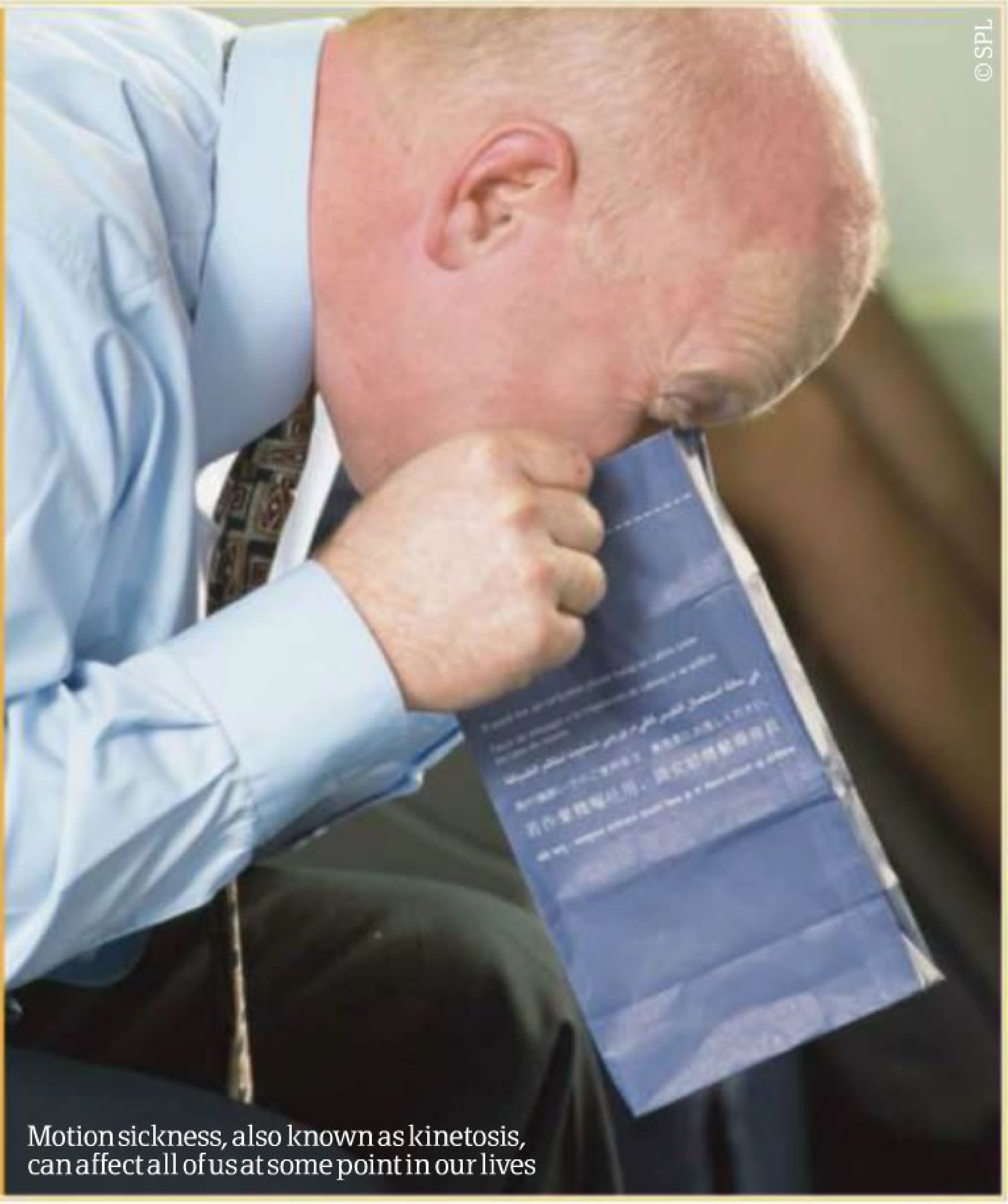
6. Mucus
Together with the offending irritant, saliva and mucus from inside the mouth and nasal cavity are also expelled from the body at up to 160km/h (100mph).

© SPL

Why do people get motion sickness?

Balancing what your eyes see with what your ears sense can be tricky when you're on the move

A collection of nerves, channels and fluid called the vestibular system inside your ears co-ordinates equilibrium by detecting motion from sensory inputs when moving. When you shift your position, the fluid in your ear also moves, triggering nerve messages that – along with visual information from the eyes – tell the brain what's going on so it can react. However, when travelling in a coach or on a boat, for example, the atypical motion experienced by the body can cause an imbalance between what the eyes are seeing (or perhaps what they aren't seeing) and what the ears are experiencing physically. The confusion between the ears, eyes and brain can cause nausea, dizziness and/or vomiting because the brain can detect motion but not necessarily see it. This can also happen in reverse whereby the eyes may perceive movement visually while none is felt by the vestibular system, providing the brain with conflicting information that can't be processed quick enough to enable the body to respond and maintain balance.

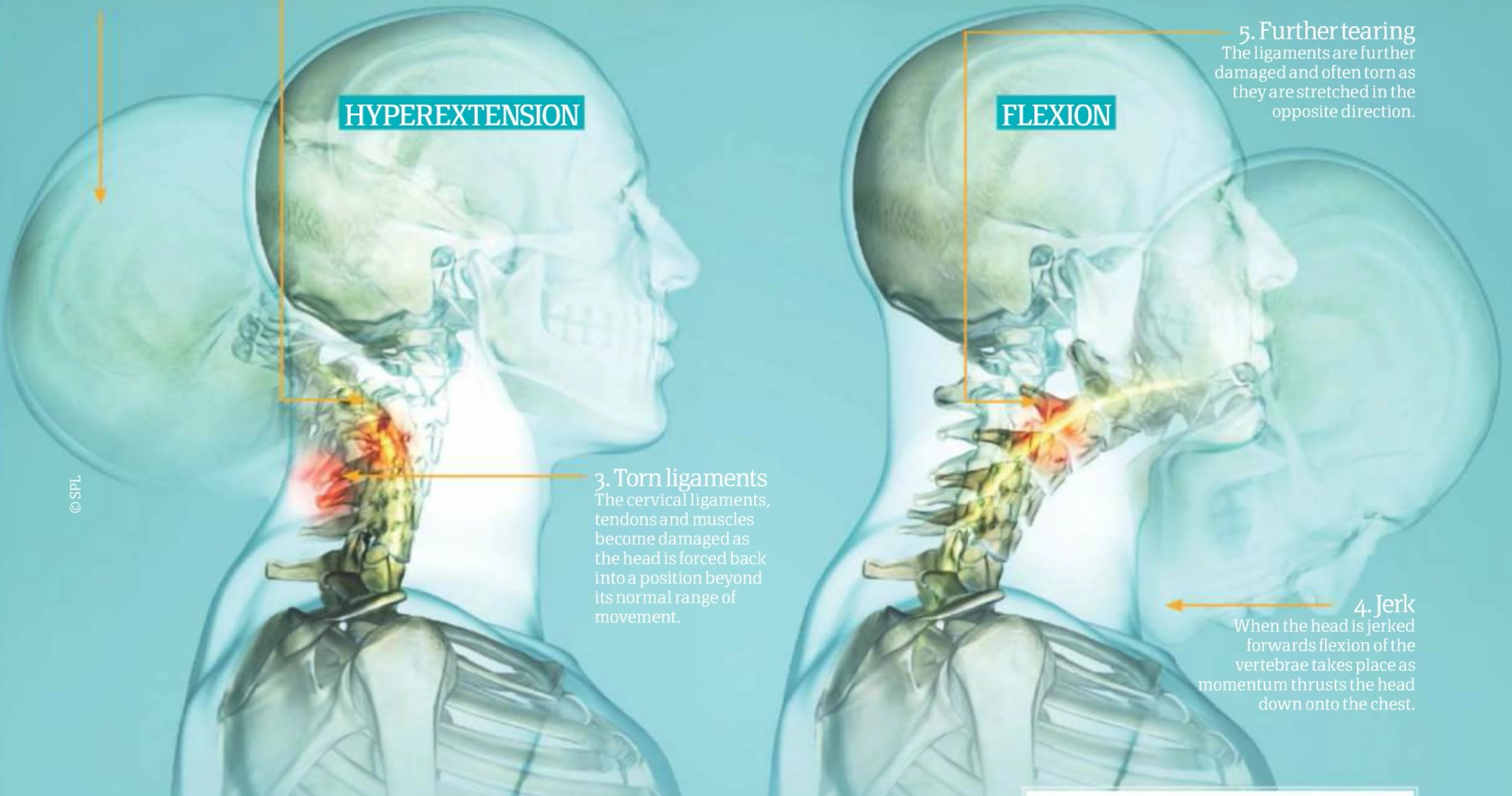


Motion sickness, also known as kinetosis, can affect all of us at some point in our lives

© SPL

Anatomy of a collision

What happens to your body when your vehicle is hit from behind?



1. Like a whip
A collision from behind causes the head to jolt backwards before quickly being whipped forwards due to momentum.

2. Intervertebral discs
The shock-absorbing intervertebral discs allow for some vertebral motion – extension (back) and flexion (forwards); during whiplash, however, they are squeezed between the vertebrae. When the nerves are pinched between two vertebrae this can cause pain or numbness.

3. Torn ligaments
The cervical ligaments, tendons and muscles become damaged as the head is forced back into a position beyond its normal range of movement.

4. Jerk
When the head is jerked forwards flexion of the vertebrae takes place as momentum thrusts the head down onto the chest.

5. Further tearing
The ligaments are further damaged and often torn as they are stretched in the opposite direction.

© SPL

What is whiplash?

What is this painful injury caused when the neck is forced outside its normal range of motion?

Whiplash is a widespread term used to describe a number of injuries caused when the neck is suddenly and quickly forced to move back and then forth, or forward then back, or even from side to side. Such movement is often the result of a traffic collision, or following a blow to the head or fall during a contact sport.

The bones of the human spine serve to protect the fragile spinal cord which is located within. Of the 33 vertebrae of the human spine, whiplash affects the seven cervical vertebrae found at the top. Vertebrae are connected to one another by bands of fibrous connective tissue called ligaments. They are also connected to the surrounding muscles by tendons. In the event of an incident, damage can be done to both of these tissues in the vicinity of the neck.

During an incident where a vehicle has struck the victim from behind, the head will be forced very quickly back and then forwards, but likewise if the sudden neck movement is due to very abrupt deceleration, the head will instead be jerked in the other direction – ie first forward and then back. Both types can result in whiplash injuries ranging from neck stiffness and loss of movement to back and shoulder pain, headaches and even numbness that can radiate down the shoulders, arms and hands.

It should be noted that although whiplash is considered a fairly minor injury, any head or neck trauma should be checked out by a medical professional. However, most muscle and tissue injuries do not show up on X-rays, so sometimes it can be difficult to diagnose. ✺

Tendons vs ligaments

While both tendons and ligaments are made of collagen cells, that's where the similarity ends. Ligaments are the tough connective tissues that link bone to bone by a joint and provide shock absorbency. They are strong and flexible bands of tissue but cannot be stretched. An overstretched ligament results in a sprain as experienced during whiplash.

Tendons, meanwhile, are the whitish fibrous cords that link one end of a muscle to a bone or other structure. Tendons look white as, unlike muscles, they don't contain many blood vessels.

A damaged ligament can often be surgically reattached to a joint bone, with mobility returning relatively quickly. A tendon, however, is part of the neuromuscular system and so electrical signals must be able to pass across the tendon to reach a muscle in order for it to react. Treatment typically involves a rest period, with a support, and then a gradual return to exercise.

Can people really be hypnotised?

Supernatural mind control, placebo effect or something in between? Hypnosis takes us on a journey into the mind…

In its simplest terms, hypnosis is a process by which someone becomes less aware of conscious thought and inhibition, and more open to suggestion. Changes in the brain's neural activity can alter the subject's perceptions and emotions, enabling them to focus their thoughts and filter out distractions. One key area involved in such altered states includes the frontal lobe, which accounts for a large portion of the brain's mass and is responsible for a person's personality, emotions and long-term memory. Changing the brain's frontal lobe function in turn alters a person's subjective experience of reality, cognitive processes shift and elective actions occur without conscious volition. Other areas of the brain that are involved with altered states include: the parietal lobe, which can distort the subject's perception of space and time; the thalamus, which can induce the feeling in a subject that they're 'in a world of their own'; and the reticular formation, which receives sensory information from the outside world and determines what is important and what's not, so as to prevent us from suffering sensory overload.

Typically a hypnotist will 'induce' the subject into a highly suggestible state, via techniques such as progressive relaxation or surprise – however, a formal induction isn't a prerequisite for hypnotism to succeed. Clinical hypnosis is conducted to address both psychological and physical problems. For example, it has been used to reduce the experience of pain in severe burn victims and of women in labour, and offer relief from nausea to patients undergoing chemotherapy. Hypnosis is also used to treat those with anxiety and various phobias as well as to modify behaviour in the treatment of eating disorders and smoking cessation. Hypnotism is a form of dissociation that works by allowing the patient to respond to suggestion while ignoring competing or incompatible stimuli. This is achieved by means of existing mental faculties. People who are hypnotised have the same physical and mental abilities that they possess in a normal state. They cannot be empowered to perform acts of superhuman strength, nor can they be forced to recall events that they never retained, such as memories of their infancy.

Who can be hypnotised?

The ability to be hypnotised falls alonga normal distribution, or bell-shaped curve, with the majority of people being moderately responsive to hypnotic suggestion, and smaller numbers at the extremes, either very difficult or very easy to hypnotise. Hypnotisability – much the same as IQ – is a relatively stable quality that will remain consistent throughout adulthood.

Scientists are always searching for characteristics that will predict successful hypnotism. They have ruled out any association between hypnotisability and being 'weak willed' or gullible. Nor are people with dissociative qualities or excellent imaginations especially open to this practice. However, it does appear that people who have the ability to become completely engrossed in daydreams or music are more likely to respond to hypnosis than those who cannot.

The human brain is capable of entering an altered consciousness whereby the subject undergoes a range of conscious experiences

© Alamy

The state debate

One controversy surrounding hypnosis is the state debate. While professionals on both sides of the argument agree that hypnosis exists, they disagree about the way it takes place.

Subscribers to the state theory believe that hypnotic induction puts participants into an altered state of consciousness, which is totally discrete from normal waking reality. State theorists argue that it is this shift of state which allows for the atypical behaviour that's often observed during hypnosis.

Non-state theorists, on the other hand, maintain that the process of hypnosis moves participants along a continuum into a zone of heightened suggestibility, perhaps due to expectations or compliance, but that the mechanisms employed during hypnosis are the same as those governing normal waking experience.

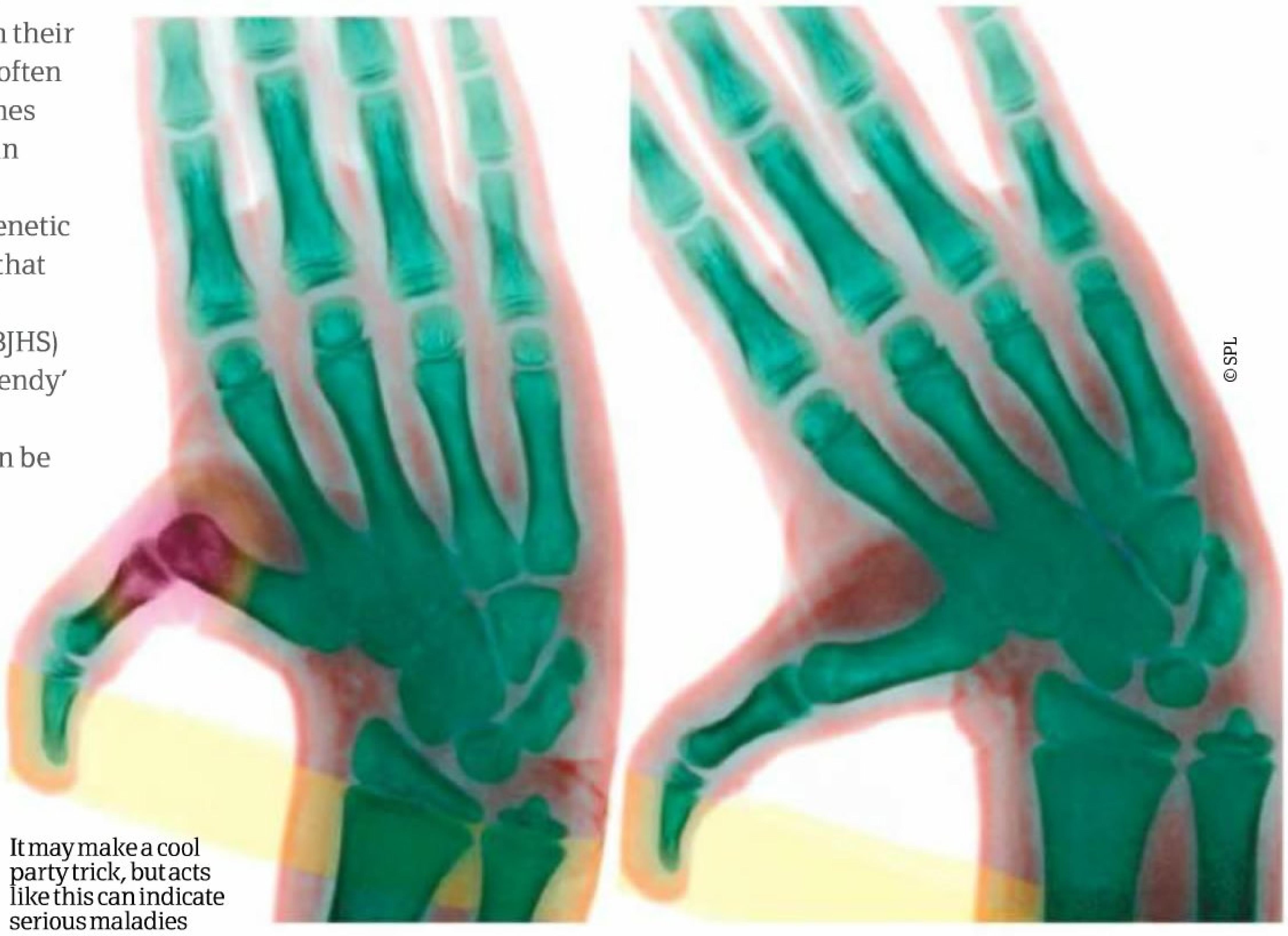
Why are some people double-jointed?

Are super-bendy people more flexible than others, or is there another explanation?

There's always one in a group: the 'double-jointed' person who can bend their thumbs back to touch their wrists, or wrap their legs behind their head. We often think of these people as especially flexible, and sometimes they are. But often hypermobile joints are indicative of an underlying medical condition.

Hypermobility syndrome (HMS) is a combination of genetic conditions that lead to muscles, tendons and ligaments that are formed differently, and are usually more fragile and prone to injury. Benign joint hypermobility syndrome (BJHS) can be considered a low level of hypermobility where 'bendy' joints can result in some pain but no life-threatening complications. Marfan syndrome, on the other hand, can be much more serious: in addition to limb dislocation, sufferers of the more serious form can experience problems with their vision, nervous system and potentially fatal heart problems, all as a result of weakened connective tissues.

Clinical diagnosis of hypermobility syndrome is made using the Beighton score, a nine-point criteria that requires the suspected HMS patient to attempt certain postures and thus confirm or rule out certain conditions. Treatment might include pain-killing drugs, although a high level of fitness and a healthy lifestyle will often help in milder cases.



© SPL

It may make a cool party trick, but acts like this can indicate serious maladies

How do hand warmers work?

How does science keep your hands toasty?

Hand-warming pads use a solution inside a closed environment with a high freezing temperature to provide a warming effect. A hand warmer starts out at room temperature but, when a metal disc is pressed into the solution, an exothermic reaction is triggered, releasing heat.

Basically, hand warmers use a solution of water and another substance, like sodium acetate. The latter raises the freezing temperature of the solution. In this instance, sodium acetate freezes at 54 degrees Celsius (130 degrees Fahrenheit) but can exist as a supercool liquid with water at a much lower temperature until the crystallisation (or freezing) process is initiated. When the metal disc in the hand warmer is pressed into the supersaturated solution, a few of the molecules of the solution jump into a solid frozen state, in turn causing the rest of the liquid to solidify. This makes the liquid leap to sodium acetate's freezing temperature. By heating the hand warmer further the frozen sodium acetate will melt, allowing it to again be stored as a supercool liquid until its next use.

To Recharge:
Pour Activer:

Chemical hand warmers can be stored at room temperature and below, but will warm when a metal disc is pressed into the solution

How does mosquito spray work?

Why do these blood-sucking insects lose their appetite after a squirt of this spray?

Repellent like DEET, or N,N-diethyl-m toluamide, deters mosquitoes from making you their next meal

Mosquitoes are attracted to humans and other warm-blooded vertebrates by sweat and the heat from our bodies. It's only actually the female of certain species of mosquito that will feast on our blood in order to feed her offspring and the only way you can stop her from doing that – and thereby preventing an itchy bite and potential disease – is by making your skin a far less appealing prospect to mosquitoes.

DEET is an acronym for a chemical compound that was developed by the US Army following World War II. Like many other insect repellents – both natural and synthetic – it essentially makes your skin a very nasty-smelling place for the mosquito to land and feed on.

It can be toxic in high concentrations, though as long as the DEET-based repellent is applied responsibly, it's both safe and usually very effective.

> "DEET-based repellent is both safe and usually very effective"

How does washing detergent get our clothes clean?

Discover the chemistry at work inside your washing machine

The secret to white whites is all in the chemistry…

Grime buster
Surfactants in detergent break down the bonds in water molecules so that they can react better with any molecules of dirt.

Anionic surfactants are the workhorse ingredients of most washing detergents. They are compounds such as sodium alkyl sulphate and are made up of molecules that have opposite charges at different points (polar molecules). Water is also made of polar molecules and, when mixed with washing detergent, the hydrophilic (water-loving) part of the surfactant molecule attracts to the water molecule, while the hydrophobic (water-hating) part of the molecule adheres to the dirt and grease in your clothes. This makes the dirt and grime more soluble in the water, allowing for easier removal from your clothing.

Another cleaning effect surfactants have is to lower the surface tension of water. Surface tension is created by these polar molecules pulling on one another due to their charge. This accounts for how pond skaters walk on water and why beads of water hang suspended on grass. By lowering the surface tension, the water can become more 'wet' and permeate clothes better allowing for a deeper clean.

MARKS & SPENCER
COLOURS
SUPER CONCENTRATED BIOLOGICAL GEL
HELPS CARE FOR COLOURS EVEN AT 15°C
WITH COLD CLEANING ACTION
630ml℮
18

What is gas?

This classic state of matter can be difficult to see but it has some amazing properties

Along with liquids and solids, gases are one of the three major states of matter. Typically they result when a substance is heated in its liquid state to its boiling point, or when evaporation occurs from the surface of a liquid. There are numerous types and classifications of gases, including elements that naturally exist in a gaseous form, compound gases comprising more than one element, and mixtures of individual pure gases.

Gas particles are much more loosely connected than those found in liquid or solid states, which results in lower density – and this is ultimately what sets a gas apart from the other two phases. Without changes in pressure or temperature, gas particles move around freely and randomly. They have no set shape and only change direction and momentum when bouncing off one another or off the inside of a container. Negatively charged areas of particles are attracted to positively charged areas – how these interact varies depending on the gas and are part of what makes each one unique. Because most gases are colourless, they are measured by four different properties: volume, temperature, pressure and number of particles; the latter property is more commonly known as moles. When put into a container (and not pressurised) gas molecules will evenly distribute themselves.

Like liquids, gases will morph into any container, however gas particles will distribute themselves evenly

Heated air is less dense than cool air, hence why hot-air balloons rise

Expansion

Gases typically expand, or increase in volume, when they are heated. Specifically, gas molecules move apart when heated, making the gas as a whole take up more space. All gases expand at the same rate if they are under the same amount of pressure. Gases can also expand without heat if the pressure lowers. Hot-air balloons float by heating propane in its liquid state until it becomes a gas. The propane gas is ignited and expands, causing the air around it to heat as well. Hot air is less dense than cooler air, so the balloon rises.

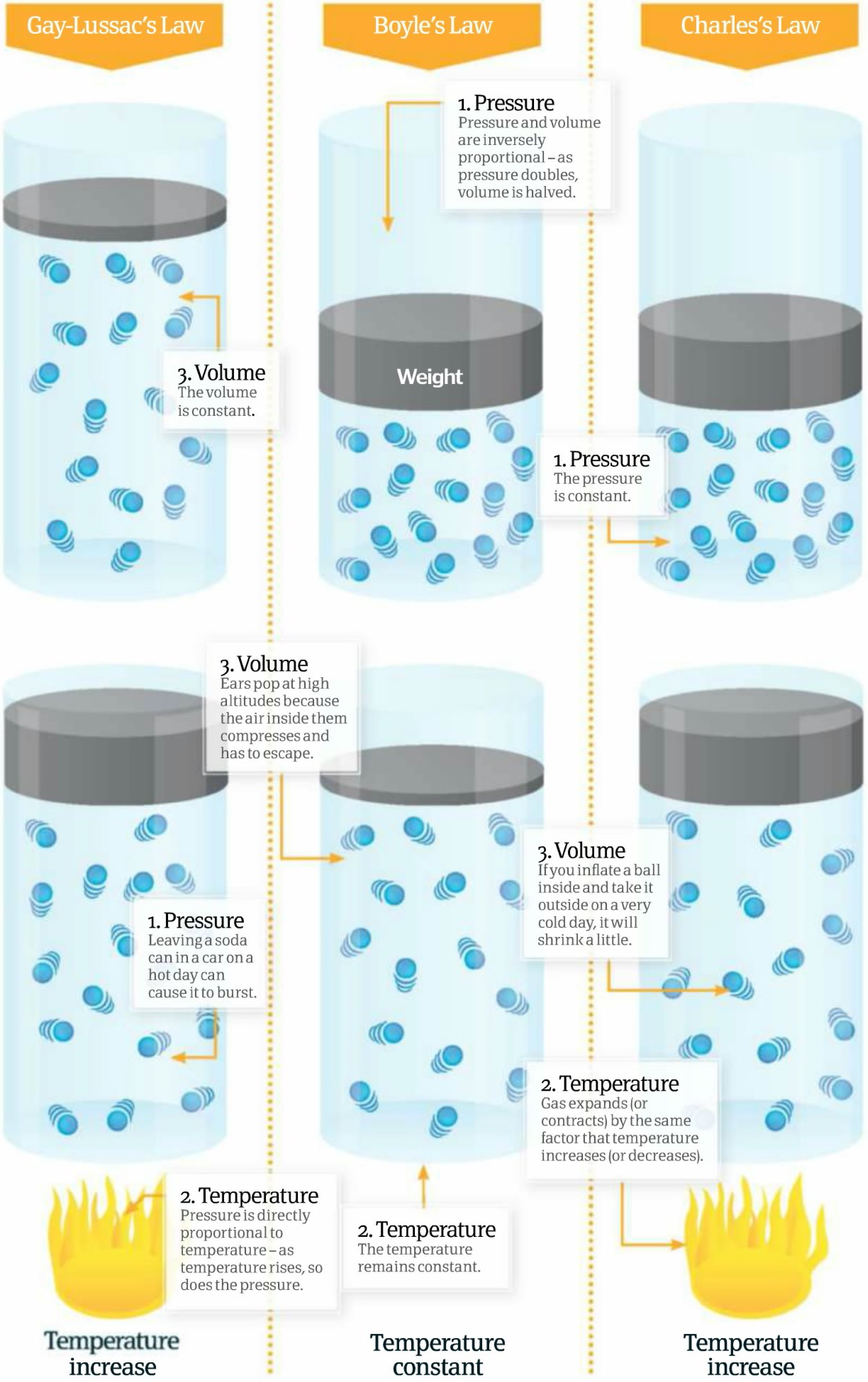
Compressing a gas raises its temperature and density

Compression

Compressing a gas means putting it under greater pressure, and this also results in an increase in temperature. This is because the molecules are closer together and they generate more energy as they collide with one another. Many gases are kept under specific pressures – usually higher pressure than that of the atmosphere – for use in various industries. Basic bicycle pumps function in the same way as pistons. Drawing up the handle pulls air into the valve; then the downstroke compresses the air and forces it into the bicycle tyre.

Understanding the behaviour of gases

Learn the laws that govern this state of matter



Gay-Lussac's Law

1. Pressure Leaving a soda can in a car on a hot day can cause it to burst.

2. Temperature Pressure is directly proportional to temperature – as temperature rises, so does the pressure.

3. Volume The volume is constant.

Temperature increase

Boyle's Law

1. Pressure Pressure and volume are inversely proportional – as pressure doubles, volume is halved.

2. Temperature The temperature remains constant.

3. Volume Ears pop at high altitudes because the air inside them compresses and has to escape.

Temperature constant

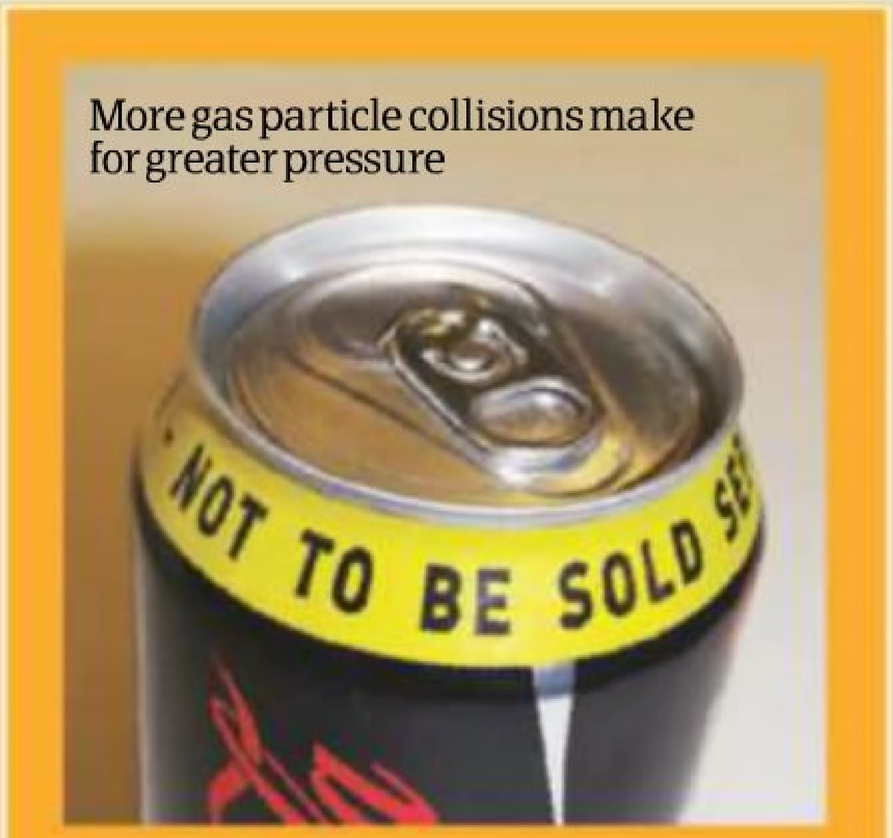
Charles's Law

1. Pressure The pressure is constant.

2. Temperature Gas expands (or contracts) by the same factor that temperature increases (or decreases).

3. Volume If you inflate a ball inside and take it outside on a very cold day, it will shrink a little.

Temperature increase


More gas particle collisions make for greater pressure

Under pressure

When a gas is under pressure in a container, it's exerting force against the inside of that container. Gas particles travel around in straight lines until they collide with one another and the walls of the object holding them; this changes their momentum and creates pressure. If you shake a can of soda before opening it, you'll have quite a mess; this is a result of the carbon dioxide gas sitting on top of the soda, along with the gas that's dissolved in the liquid itself. Shaking it forces the extra gas into the liquid, creating large bubbles that rapidly push their way out as you open the can.

Vapour is a sort of halfway point between gas and liquid states

Vapour

Vapour is a gaseous phase in which a substance is at a slightly lower temperature than its critical point – the conditions, like temperature and pressure, under which it changes to a different state of matter. When it reaches its critical point, it can be condensed. A vapour is a sort of halfway state. Substances can also exist in both states at the same time. One example occurs when boiling water. Once water reaches its boiling point, it begins to turn to a gas; in the case of boiling water, we better know the vapour as steam.

How is electricity conducted with no resistance?

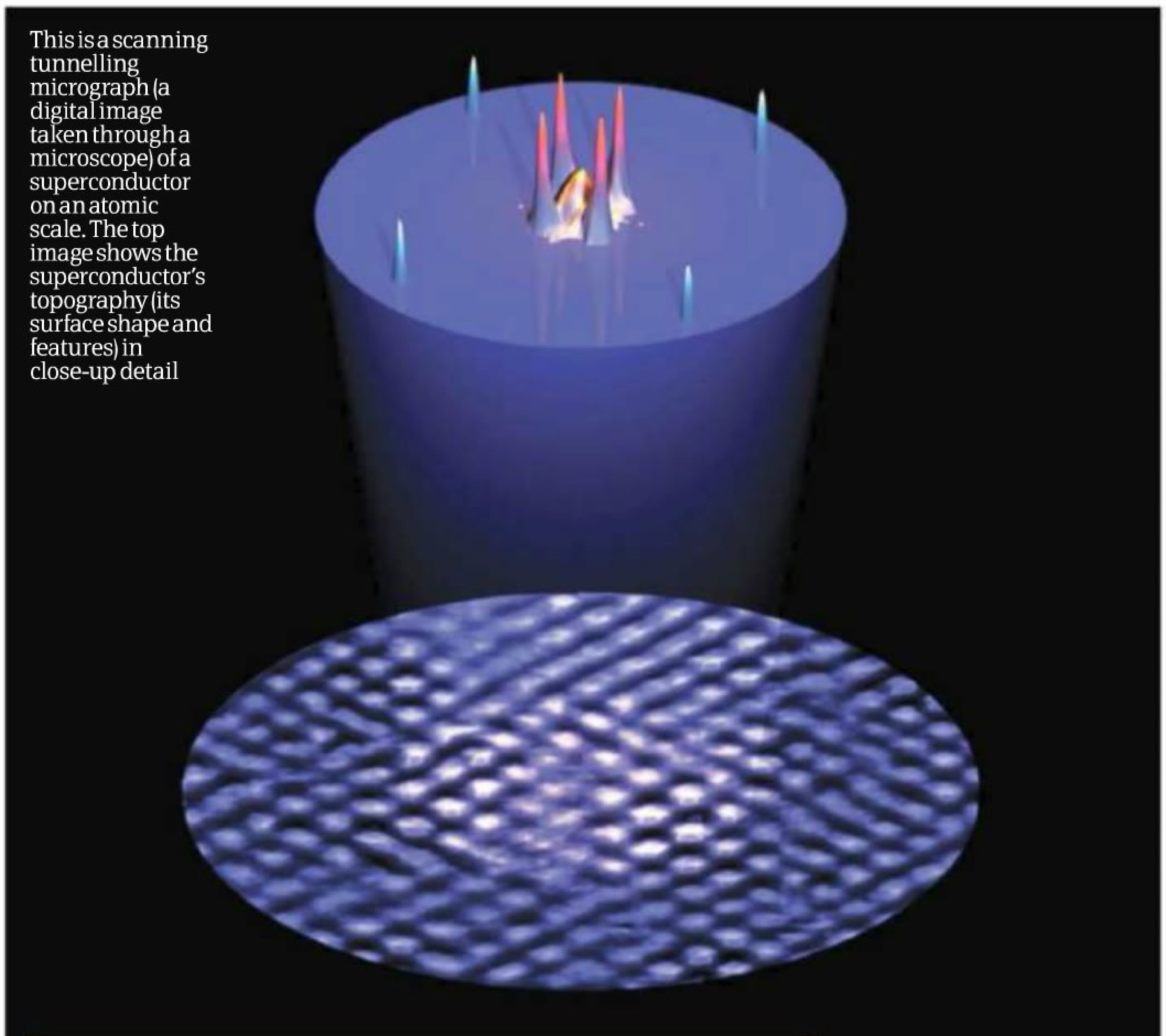
Superconductors may seem like perfectly ordinary materials, but turn down the thermostat and their superpowers are revealed…

Superconductors are metals (such as lead) or oxides which conduct electricity with no resistance. There's just one catch – to display their superpowers, they need to be kept at a frosty -260 or so degrees Celsius (-436 degrees Fahrenheit).

Peer inside a chunk of lead and you'll see row upon row of neatly packed ions, bathed in a swarm of electrons. These loose electrons are what conduct electricity – set them into motion and you have an electrical current. At room temperature, the lead ions vibrate away frenetically. From an electron's perspective, it's like trying to negotiate a crowded dancefloor without spilling your drink. Constant collisions between electrons and ions convert electrical energy into heat; this is resistance.

Turn the temperature down a few hundred notches though and the ion vibrations subside, creating a stable lattice. Now, as electrons flow through, a new effect comes into play: distortions in the lattice force them into pairs. These unlikely unions trigger a weird quantum physics quirk: electron pairs throughout the material coalesce into a perfectly synchronised cloud, moving a bit like a school of fish. This means that the swarm of electrons can move through the lattice with no collisions, resulting in no resistance.

Thanks to this astounding property, a huge current can be run through a superconductor without it overheating. This means they can create incomparably powerful electromagnets. These are currently used in MRI scanners, supercomputers, particle accelerators (like the LHC) and levitating maglev trains.



This is a scanning tunnelling micrograph (a digital image taken through a microscope) of a superconductor on an atomic scale. The top image shows the superconductor's topography (its surface shape and features) in close-up detail

Top metal superconductors

Here are the best metal (Type 1) superconductors with their critical transition temperatures – the point at which it is necessary to cool them before they will superconduct.

Lead	7.196 K
Lanthanum	4.88 K
Tantalum	4.47 K
Mercury	4.15 K
Tin	3.72 K

Superconductor evolution

Take a journey through the last century to see just how far superconductors have come…

1911

Absolute zero

Dutch physicist Kamerlingh Onnes (right) and a student create temperatures just below absolute zero and uncover that mercury is a good superconductor.

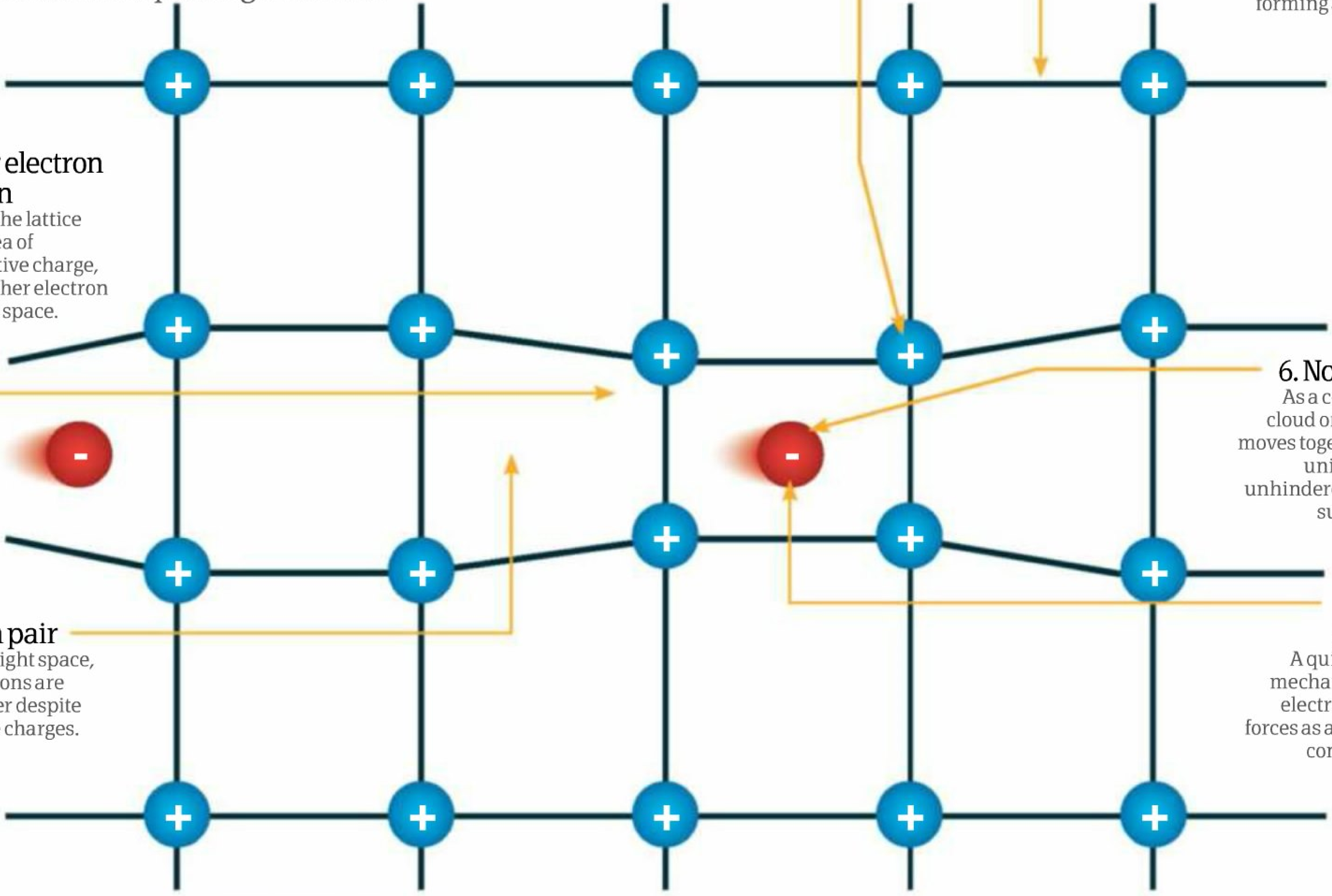
1933

Levitation

Meissner and Ochsenfeld discover the Meissner effect: the uncanny ability of superconductors to repel magnetic fields and cause magnets to levitate.

Superconductor in action

Find out how superconductors make life a whole lot easier for passing electrons



1. Frozen lattice

At temperatures approaching absolute zero, the superconductor's ions barely vibrate, forming a stable lattice.

2. Bending the lattice

As a negatively charged electron makes its way through, the positively charged ions are attracted into its path.

3. Another electron is drawn in

This bend in the lattice creates an area of stronger positive charge, drawing another electron into the same space.

4. Electron pair

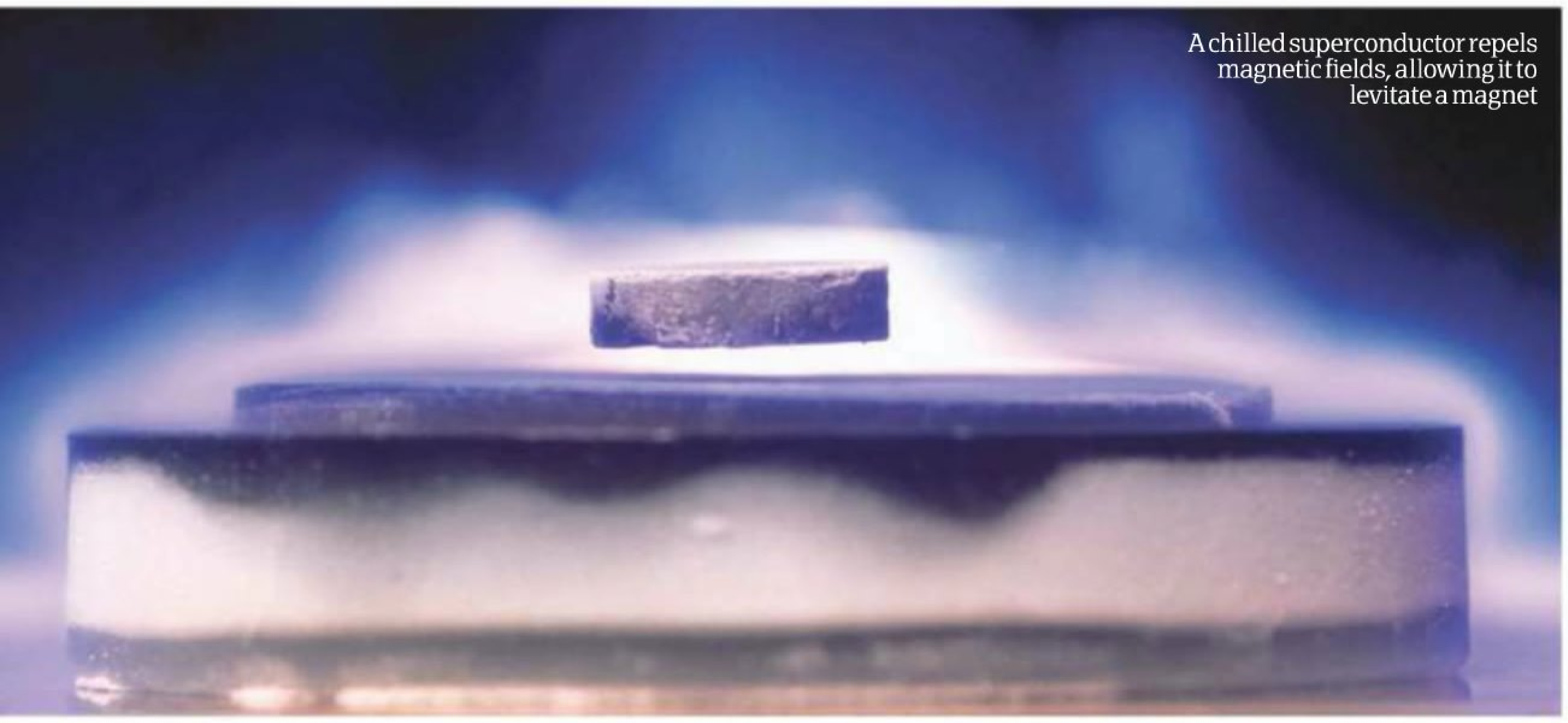
Trapped in a tight space, the two electrons are forced together despite their negative charges.

5. Electron pairs unite

A quirk of quantum mechanics allows the electron pairs to join forces as a Bose-Einstein condensate (BEC).

6. No resistance

As a condensate, the cloud of electron pairs moves together in perfect unison, travelling unhindered through the superconductor.



A chilled superconductor repels magnetic fields, allowing it to levitate a magnet

1935
Brothers London

Fritz and Heinz London reconcile superconductor theory to show that zero resistance and the Meissner effect stem from the same phenomenon.

1957
BCS

Bardeen, Cooper and Schrieffer propose the BCS theory of superconductivity, explaining electron pairing. It earns them a Nobel prize.

1986
Hot stuff

Bednorz and Müller discover the first 'high-temperature' superconductor, which works its magic up to -243°C (-405°F).

2009
Hotter stuff

Today's superconductivity temperature record is set by mercury barium calcium copper oxide, which acts as a superconductor up to a 'blistering' -138°C (-211°F).

The potential of superconductivity

Despite their impressive abilities, most current superconductor technologies remain chained to hi-tech science laboratories, burdened by bulky, energy-greedy and very expensive cooling systems in order to function.

Scientists have, however, set their sights on creating a superconductor that works at room temperature, which could bring cutting-edge technologies into all of our day-to-day lives. Inexpensive, portable MRI scanners could drastically improve healthcare, while superfast maglev trains would zip up and down the country, considerably reducing travel times.

Replacing our inefficient electrical grids with superconducting cables would slash our electricity bills. It could also give renewable energies – such as wind farms – which are often located great distances from our cities a much deserved boost. Elsewhere, superconductor-enabled electronics could see smaller, faster computers hit the high street in the future.

While physicists have created superconducting materials operational at temperatures up to a 'balmy' -138 degrees Celsius (-211 degrees Fahrenheit), the mechanism behind these is not yet understood. Many still believe that the Holy Grail of room temperature superconductors is achievable – it's just a matter of time and patience before we discover it.

© SPL

What's the lightest material in the world?

Discover how Aerographite was developed, how it compares to other materials and what unique applications it might offer in the future

Aerographite is a revolutionary new material that consists of a network of porous carbon tubes. These tiny tubes are three-dimensionally interwoven at both a nano and micro level, creating a substance that weighs only 0.2 milligrams per cubic centimetre (0.0001 ounces per cubic inch); it is about 99.99 per cent air.

Aerographite appears jet-black – as its structure means that it absorbs almost all visible light, can conduct electricity and, most importantly, is incredibly ductile – the latter quality allowing it to be drawn out and manipulated, something that grants it a wide range of applications.

The reason that aerographite is so light is three-fold. Firstly, the carbon tubes are not solid but actually empty shells. Secondly, carbon has a very low atomic mass – far more so than the previous lightest material in the world which was nickel based. And thirdly, in addition to the tubes being hollow, their walls are also porous. Combined, this trio of characteristics generates a material that is 75 times lighter than Styrofoam and a staggering 56,700 times lighter than lead.

Such a complex material requires, as you would expect, an equally complex manufacturing process.

Aerographite is made by first building a kind of skeleton, or frame, out of crystallised zinc oxide, which is achieved by heating zinc oxide powder to 900°C (1,652°F) in an oven. From this crystallised material, a kind of pill is created in which a matrix of zinc-oxide micro and nano-tetrapods develop. The four-sided jack-shaped tetrapods interweave and construct a stable entity of particles to form the skeleton.

The skeleton-filled pill is then deposited into a reactor for chemical vapour deposition. Here, a streaming gas atmosphere enriched with carbon covers the skeleton with a graphite coating only a few atomic layers thick. It is this coating that creates the web-like structures of the aerographite. Once this is achieved, hydrogen is introduced to the chamber, which reacts with the oxygen in the zinc oxide tetrapod skeleton, causing it to vaporise and leak out through the porous walls of the graphite coating. This process leaves hollow tubes of super-light aerographite, which can then be extracted.

Aerographite comparison

1. Lead

With this heavy metal clocking in at 11,340 milligrams per cubic centimetre (6.5549 ounces per cubic inch), aerographite smashes it in terms of weight, with the new material roughly 56,700 times lighter.

2. Aluminium

The supposedly super-light metal aluminium weighs 2,700 milligrams per cubic centimetre (1.5607 ounces per cubic inch). Nevertheless, it is still nowhere near as light as aerographite, which is 13,500 times lighter than it.

3. Bone

Super-strong and light, bone weighs 1,850 milligrams per cubic centimetre (1.0694 ounces per cubic inch), which is over six times lighter than lead. But this organic material remains some way off aerographite, with the latter weighing 9,250 times less.

4. Cork

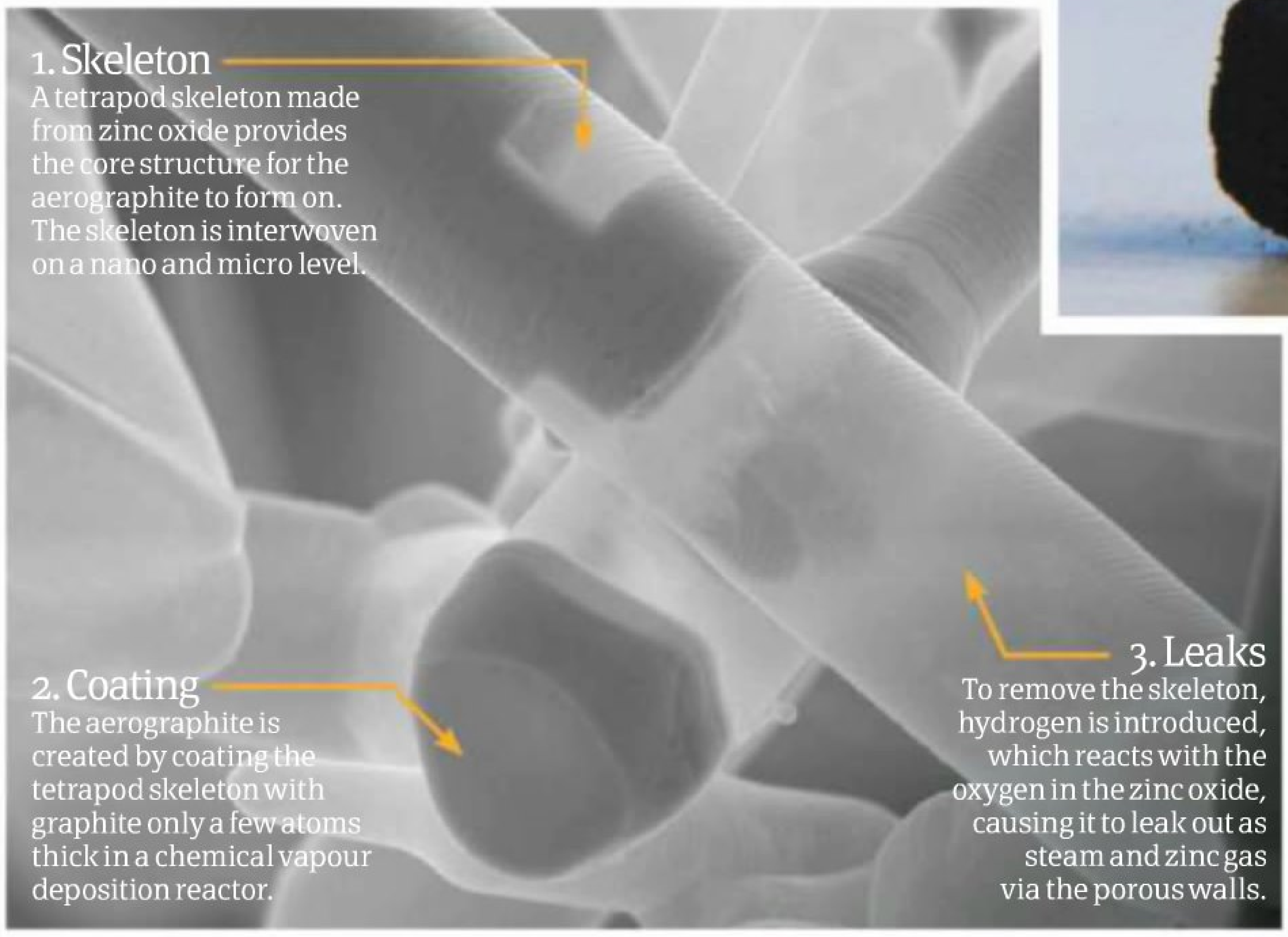
Cork is so light that it can float on water. However, at 160 milligrams per cubic centimetre (0.0924 ounces per cubic inch), cork is still approximately 800 times heavier than aerographite.

5. Nickel microlattice

Famous for being so light it could rest on a dandelion seed head, at 0.9 milligrams per cubic centimetre (0.0005 ounces per cubic inch) aerographite is impressively four times less heavy.

How is aerographite made?

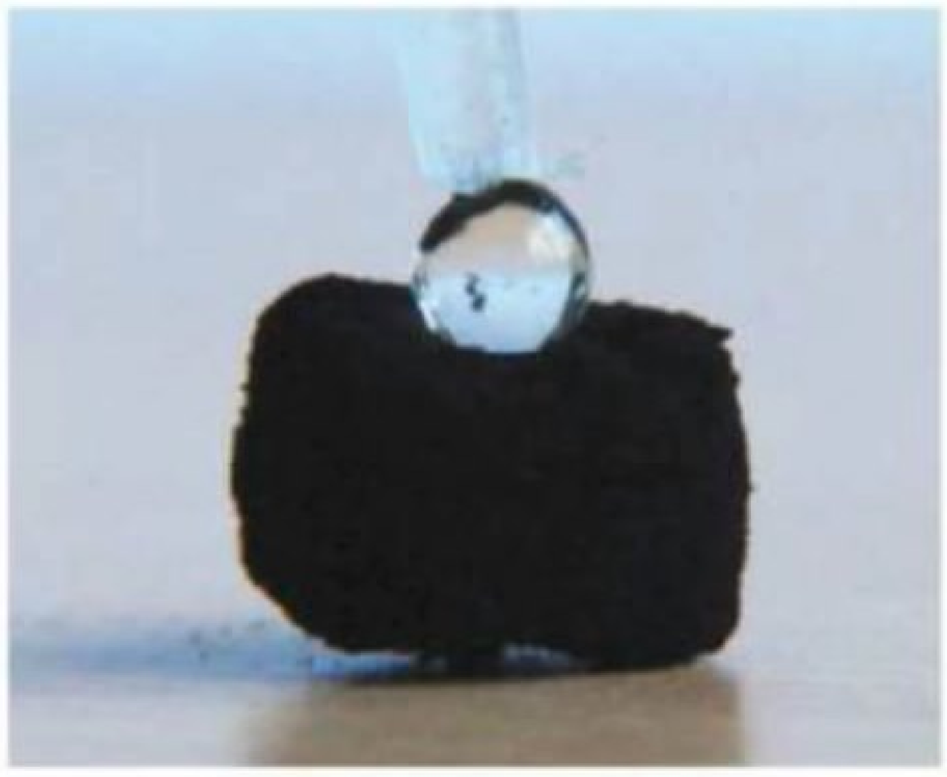
We take a look at the unique material under the microscope to reveal how it forms



1. Skeleton
A tetrapod skeleton made from zinc oxide provides the core structure for the aerographite to form on. The skeleton is interwoven on a nano and micro level.

2. Coating
The aerographite is created by coating the tetrapod skeleton with graphite only a few atoms thick in a chemical vapour deposition reactor.

3. Leaks
To remove the skeleton, hydrogen is introduced, which reacts with the oxygen in the zinc oxide, causing it to leak out as steam and zinc gas via the porous walls.



Above shows a block of aerographite supporting a drop of water. It appears black in colour as its carbon tubes absorb almost all visible light

© Kiel University; NASA

What is a vacuum?

Is empty space really empty, and how can we find out?

A vacuum is a space that has less gaseous pressure than the standard atmospheric pressure at sea level on Earth. A partial vacuum can be easily created by simply pumping air out of a container. If the container is not sealed, though, the air will be replaced fairly quickly.

In everyday life, vacuums are used in light bulbs, cathode ray tubes, cleaning appliances, and to package, protect and preserve a range of foodstuffs. Creating a vacuum drove the piston mechanism in the Newcomen steam engine and was also used in the braking systems of trains. Household vacuum cleaners work by sucking in air, which creates a lower air pressure than that outside the device. To restore the partial vacuum the outside pressure forces air, and with it dirt/dust etc, into the appliance.

The purest vacuums can be found in outer space. Between galaxies, the vacuum density drops to ~0.001 atoms per cubic centimetre, while in the void between stars in the Milky Way, the vacuum is ~0.1-1 atoms per cubic centimetre. This is in contrast to a vacuum cleaner that produces a vacuum of around 1019 molecules per cubic centimetre, though sophisticated extreme-high vacuum (XHV) lab chambers have achieved a vacuum of fewer than 1,000 molecules per cubic centimetre.

Whether manmade or natural, there is no such thing as a perfect vacuum. Even in a virtually complete vacuum, physicists have discovered the presence of quantum fluctuations and vacuum energy.

The characteristics of a vacuum

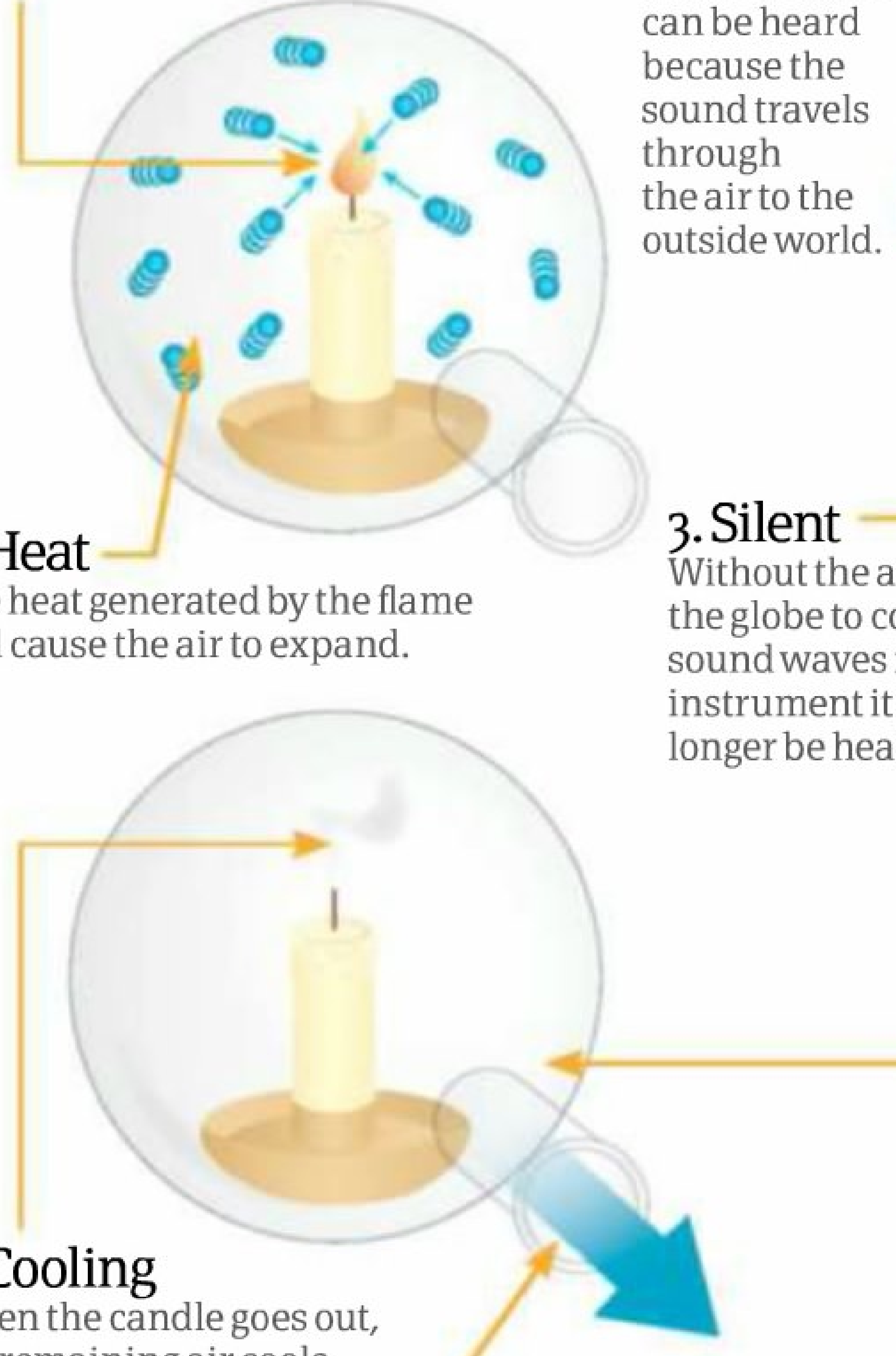
The amount of air pressure on our planet reduces the higher you travel in the atmosphere. At sea level, we experience one kilogram per square centimetre (14.7 pounds per square inch) of pressure produced by air molecules. At 15 kilometres (ten miles) air pressure reduces to 0.12 kilograms per square centimetre (1.6 pounds per square inch), and in outer space, there's no air pressure. This means it's easier to obtain a vacuum the further you travel from Earth's surface. Another characteristic of a vacuum is that it does not transfer heat by convection nor conduction; this property inspired vacuum flasks, which use a vacuum sandwiched between an outer and an inner wall to keep liquids hot/cool for extended periods.

Finding something in nothing – the science of the vacuum

© NASA

Flames inside a vacuum

The lack of air in a vacuum starves a naked flame of oxygen causing it to extinguish



1. Candle
The candle flame consumes the oxygen in the globe.

2. Heat
The heat generated by the flame will cause the air to expand.

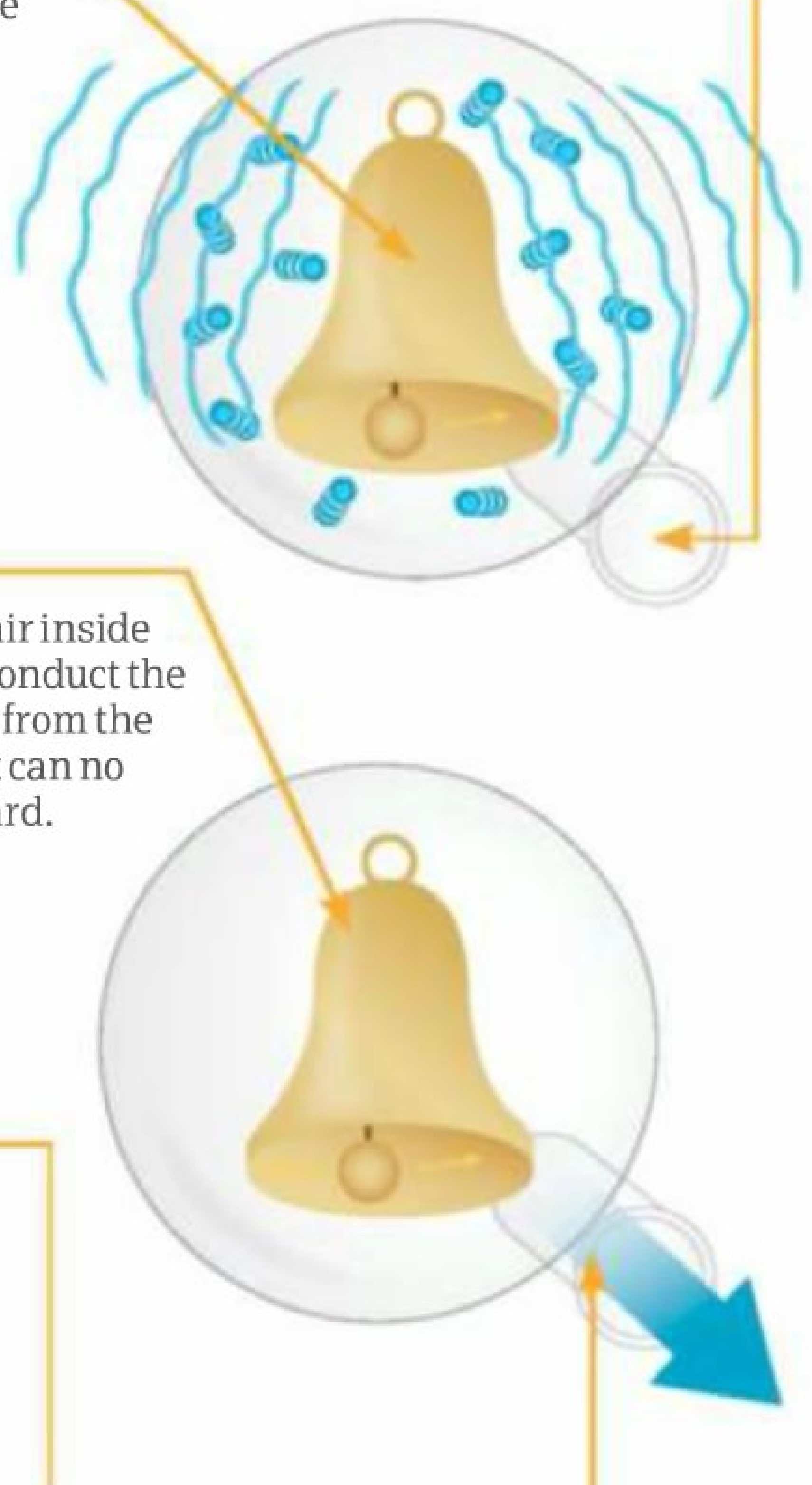
3. Expansion
The expanding hot air escapes from the globe.

4. Cooling
When the candle goes out, the remaining air cools down and contracts.

5. Vacuum
A partial vacuum will now be created; if the vessel is not sealed the outside air pressure will send air back into the globe.

Sound in a vacuum

Vacuums induce silence because sound waves require air to travel



1. Bell
A ringing bell inside the globe can be heard because the sound travels through the air to the outside world.

2. Vacuum
If air is pumped out of the globe, it will create a vacuum.

3. Silent
Without the air inside the globe to conduct the sound waves from the instrument it can no longer be heard.

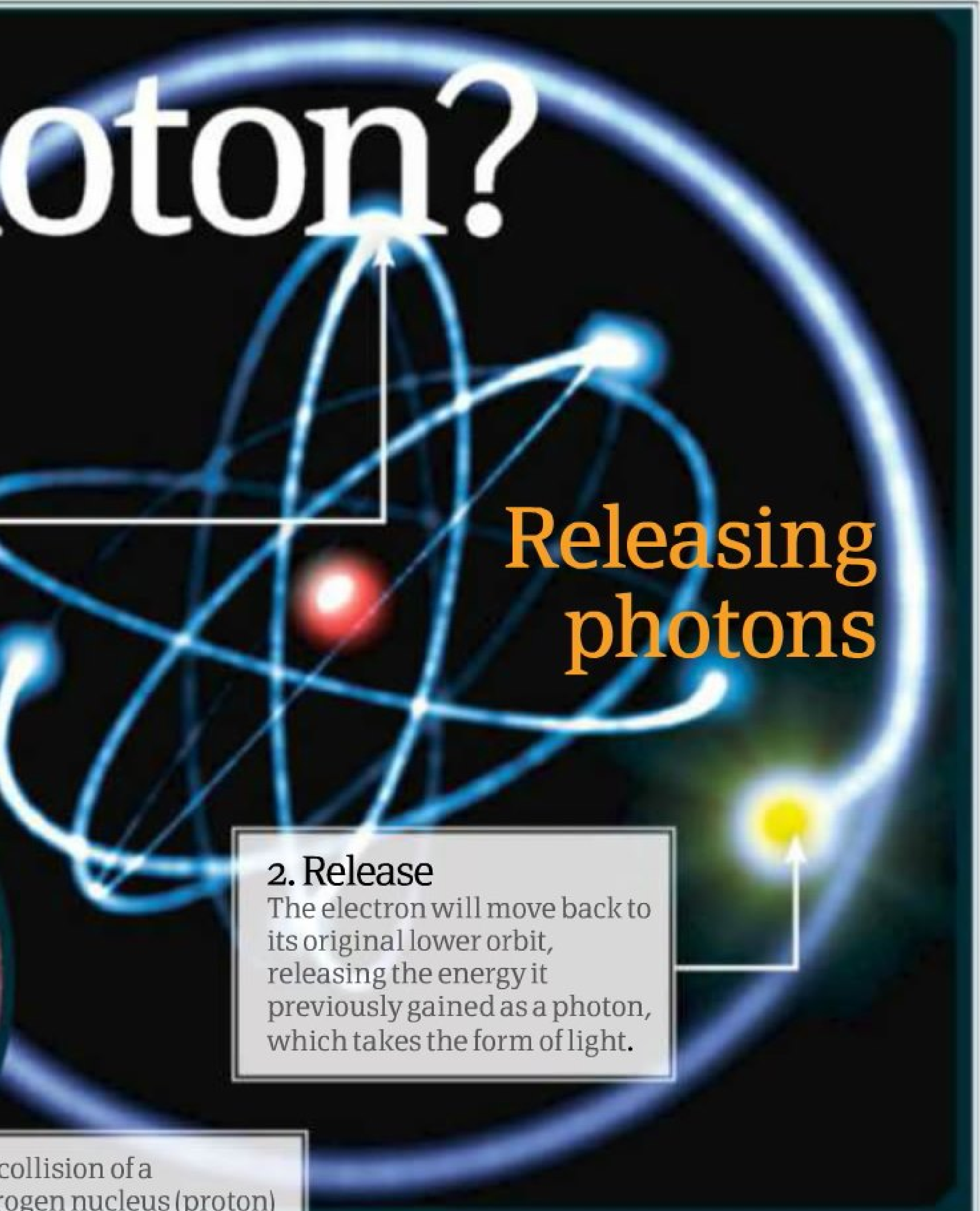
4. Seal
If the globe is unsealed to allow the outside air pressure to fill it up again, the sound of the ringing bell will return.

What is a photon?

Just how do these tiny packets of light work?

A photon is one of the elementary particles of the universe and is accountable for much of its basic structure. Photons are responsible for one of the fundamental forces of nature – the electromagnetic force – and are often regarded by many as the basic unit of light. They are also responsible for forces in an electromagnetic field and are the main constituent of light that enables it to travel throughout the cosmos.

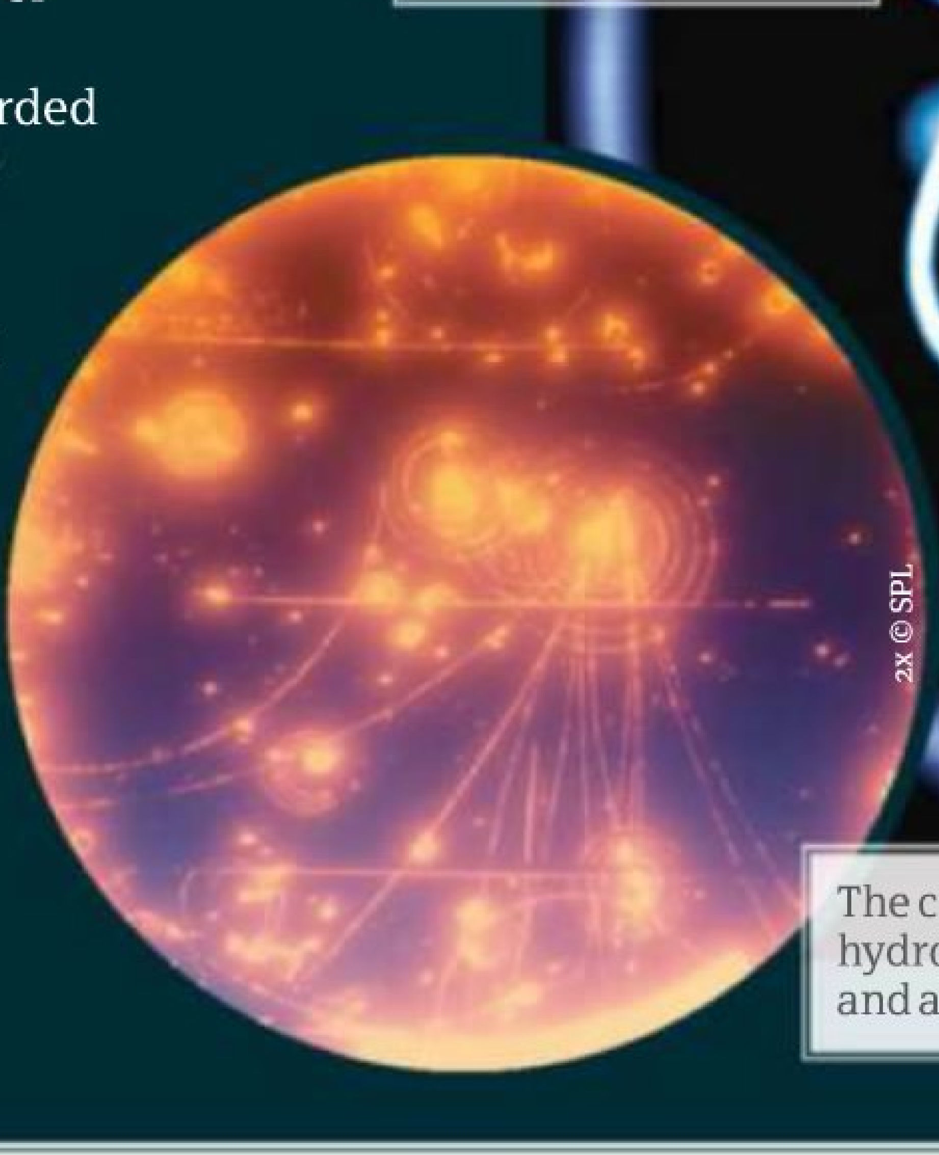
Photons are basically little packets of energy, or electromagnetic waves, but they contain no mass or electrical charge whatsoever. They are released from atoms when a change in energy occurs, travel at the speed of light and can exist as both a wave and as a particle. When we see light, what we are really observing is the emission of photons from agitated atoms.



Releasing photons

1. Energy
If an atom absorbs enough energy, an electron can become excited and move to a higher-energy orbit.

2. Release
The electron will move back to its original lower orbit, releasing the energy it previously gained as a photon, which takes the form of light.



2x © SPL

The collision of a hydrogen nucleus (proton) and a high-energy photon

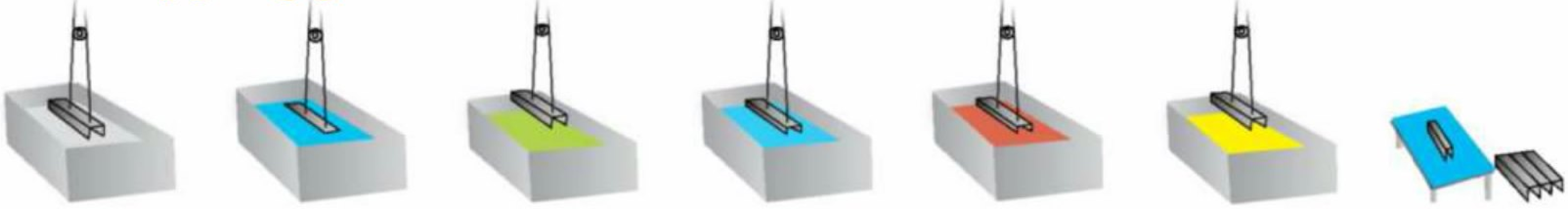
How can steel be made stronger?

Read on to discover how the strength of steel can be bolstered even further through the use of some rather clever chemical reactions

Steel has been around for millennia, ever since it was discovered that introducing carbon to the forge produced a much harder and durable metal than iron. Like iron though, it's still susceptible to the elements: exposed to moisture and oxygen in the air, it's prone to corrosion and rust. So, in the 18th and 19th centuries, heavy industry led to the process of curing steel – otherwise known as galvanising.

Hot-dipping is the most common method of galvanisation. It involves a final stage of dipping steel into a bath of molten zinc at around 460 degrees Celsius (860 degrees Fahrenheit). The zinc bonds with the steel, forming iron-zinc alloys which, in turn, forms zinc oxide on the surface. As it's the zinc that's effectively rusting and not the iron, the zinc oxide layer helps protect the steel, increasing its life span from around five years to anything up to 70 years.

Hot-dipping galvanisation



Caustic cleansing
Dirt, grease and oil is removed with a caustic alkaline solution.

Rinsing
The steel is rinsed in water to wash off the caustic solution.

Pickling
The surface is refined further with acid 'pickling', to remove rust and scale.

Rinsing
Another rinse to remove the acid.

Flux solution
A dip in zinc ammonium chloride removes oxides and prevents oxidation prior to the next step.

Molten zinc bath
The steel's final dip is in a bath of molten zinc at 435-455°C (815-850°F).

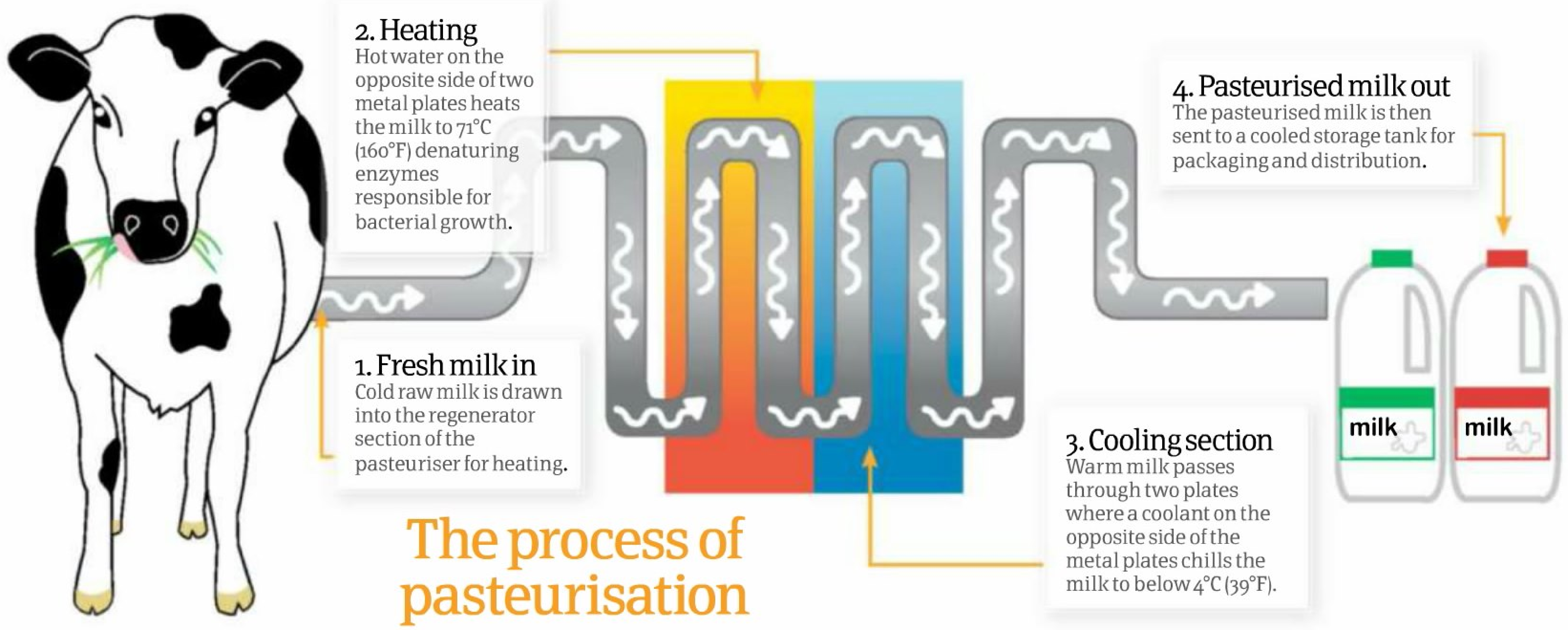
Cooling and cleansing
The galvanised steel is then left to cool and any excess zinc drains away.

Why do we pasteurise milk?

Find out how pasteurising food increases the shelf life of many products

Pasteurisation is a process of heating food and liquid to a specific temperature in order to slow microbial growth, giving it a longer shelf life. This technique is usually associated with milk where it reduces the number of potentially harmful bacteria such as E coli and salmonella that are present in its raw state.

Bacteria produce enzymes which help them to break down and digest a wide range of organic materials allowing them to divide and conquer. Heating milk to 71 degrees Celsius (160 degrees Fahrenheit) for 15 seconds changes the shape of the enzymes in the harmful bacteria, rendering them useless and hindering the bacterial growth and multiplication process. Pasteurisation does not stop all the bacteria, which is why you still need to keep it in the fridge. It does, however, significantly lower the concentration of harmful bacteria, leaving your stomach to do the rest of the work.



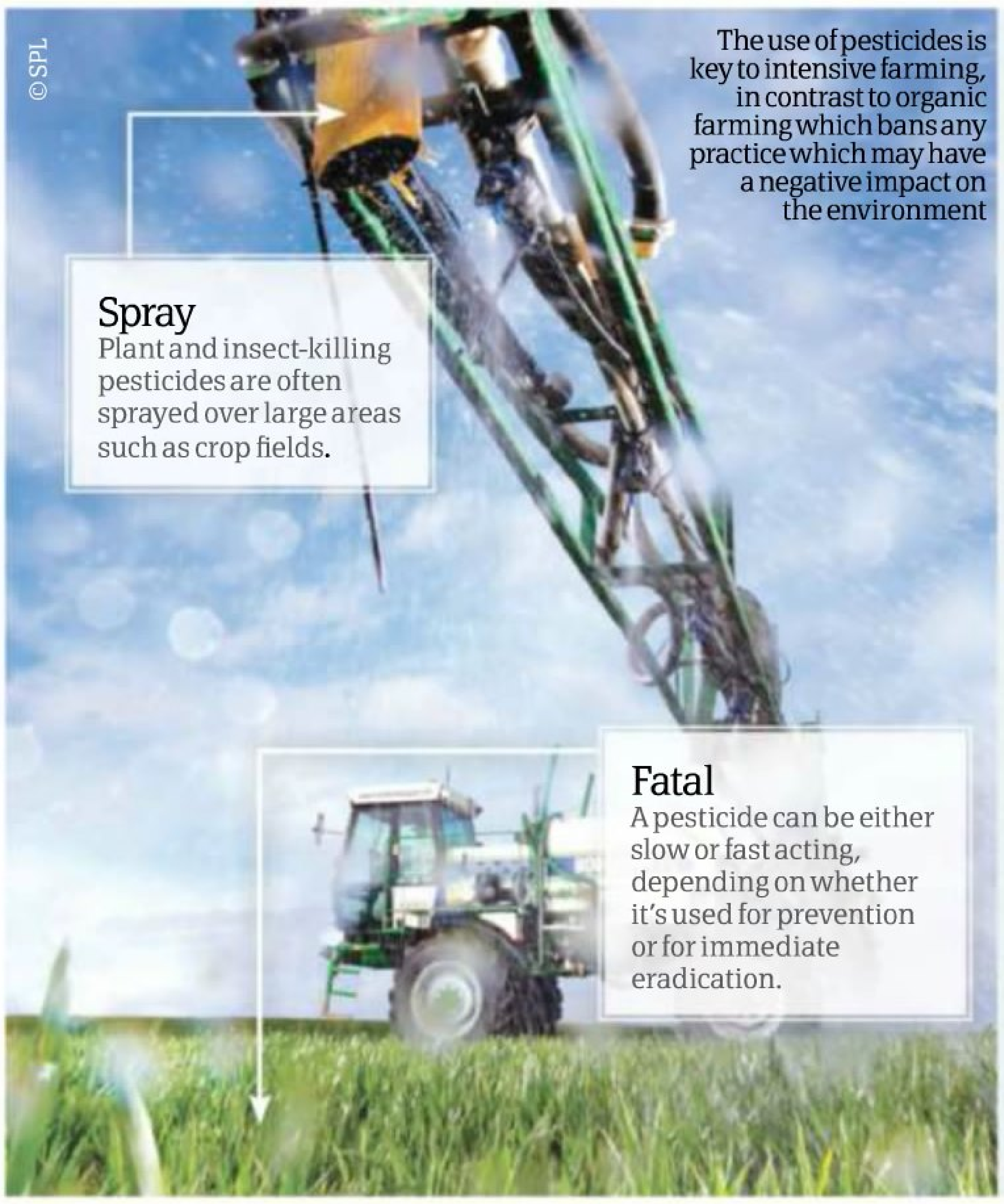
The process of pasteurisation

1. Fresh milk in
Cold raw milk is drawn into the regenerator section of the pasteuriser for heating.

2. Heating
Hot water on the opposite side of two metal plates heats the milk to 71°C (160°F) denaturing enzymes responsible for bacterial growth.

3. Cooling section
Warm milk passes through two plates where a coolant on the opposite side of the metal plates chills the milk to below 4°C (39°F).

4. Pasteurised milk out
The pasteurised milk is then sent to a cooled storage tank for packaging and distribution.



© SPL

The use of pesticides is key to intensive farming, in contrast to organic farming which bans any practice which may have a negative impact on the environment

Spray
Plant and insect-killing pesticides are often sprayed over large areas such as crop fields.

Fatal
A pesticide can be either slow or fast acting, depending on whether it's used for prevention or for immediate eradication.

How do pesticides kill pests?

The science of terminating bugs and other pests explained

Pesticides are mixtures of chemicals and other substances that are used to tackle pests such as weeds. Thousands of different types are in use, and some are even living organisms, such as the bacterium bacillus thuringiensis which is used to control insects. To alter, damage or destroy the life cycle of an unwanted visitor, pesticides interfere in a physical, chemical or biological manner.

The three primary methods of application are baiting, fumigating and spraying. Different pesticides have different forms of attack. Some, like tetramethrin (which is used to kill the household fly), are administered as a spray. Others are absorbed into, say, a weed and remain with it, slowly killing it from the inside. In addition, insecticides are commonly administered to crops and, when a bug attempts to consume the plant, it will be dealt a lethal dose of the killer substance. Similarly, baiting pesticides, such as rat poison, are also designed to be ingested and will only take effect once they have been absorbed into the bloodstream.

What is distillation?

The revolutionary ancient discovery that enables us to make gasoline from crude oil and vodka from potatoes

In many ways, during the Middle Ages, distillation was the alchemist's greatest tool. Through controlled heating of a liquid or solid source material, the alchemist could draw out and isolate pure vapours that were cooled, condensed into liquid and employed in the mystical medicinal research.

Distillation also helped the Ancient Greeks to purify fresh drinking water from the sea. It drew pungent oils out of flowers and herbs to be used as perfumes and early medicines. And it took humble beer and homemade wine and refined them into finely crafted, high-octane spirits that earned the name aqua vitae, or the water of life.

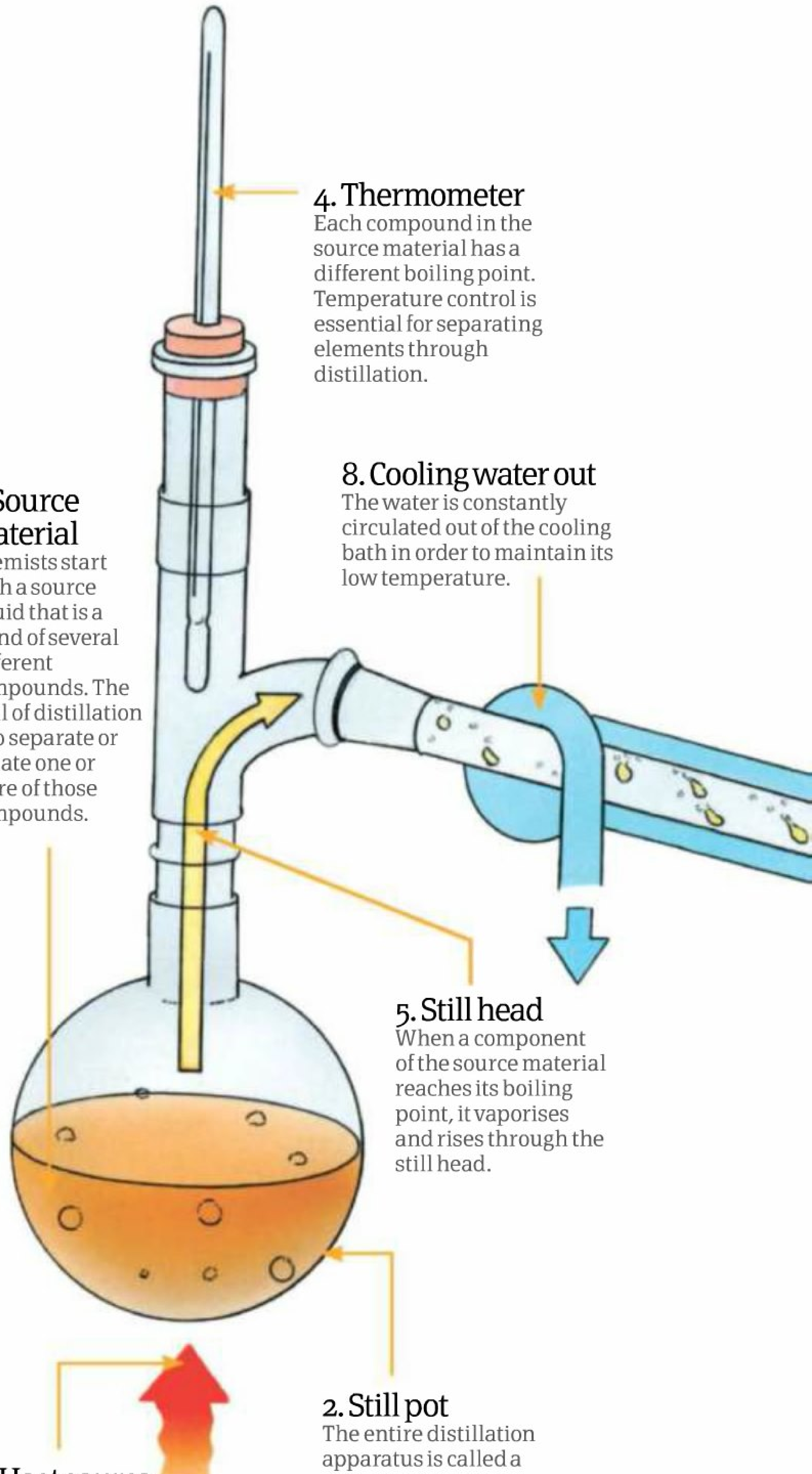
Today, distillation remains a critical chemical process for isolating pure compounds from a mixed solution. The science of distillation is rooted in the fact that every molecular compound has its own unique boiling point and dew point. The boiling point is originally reached when the vapour pressure of a liquid equals the atmospheric pressure above it, allowing molecules within the liquid to freely escape as vapour. The dew point is the temperature at which the vapour cools enough to condense and return to a liquid state.

Since compounds have unique boiling points, they can be vaporised out of a mixed solution at different temperatures. First, you slowly heat the solution to the boiling point of the compound that you want to isolate. The vapour that rises from the mixture will still contain a blend of the compounds in the solution, but a far greater concentration of the desired compound.

> "Every molecular compound has its own unique boiling point and dew point"

The rising vapour is channelled into a condensing tube, where it is cooled by a circulating water bath and then condensed back into a purified liquid.

Simple distillation is taught in school chemistry labs throughout the world, but industrial-strength distillation supplies the world with a wealth of different products, from whisky and perfume through to gasoline and liquid nitrogen, plus a lot more besides.



1. Source material
Chemists start with a source liquid that is a blend of several different compounds. The goal of distillation is to separate or isolate one or more of those compounds.

2. Still pot
The entire distillation apparatus is called a still, and the still pot holds the source material as it is heated.

3. Heat source
In laboratories, chemists use a hot plate or Bunsen burner to heat the source material. The still pot can also be submerged in a hot water or oil bath.

4. Thermometer
Each compound in the source material has a different boiling point. Temperature control is essential for separating elements through distillation.

5. Still head
When a component of the source material reaches its boiling point, it vaporises and rises through the still head.

8. Cooling water out
The water is constantly circulated out of the cooling bath in order to maintain its low temperature.

Making alcohol

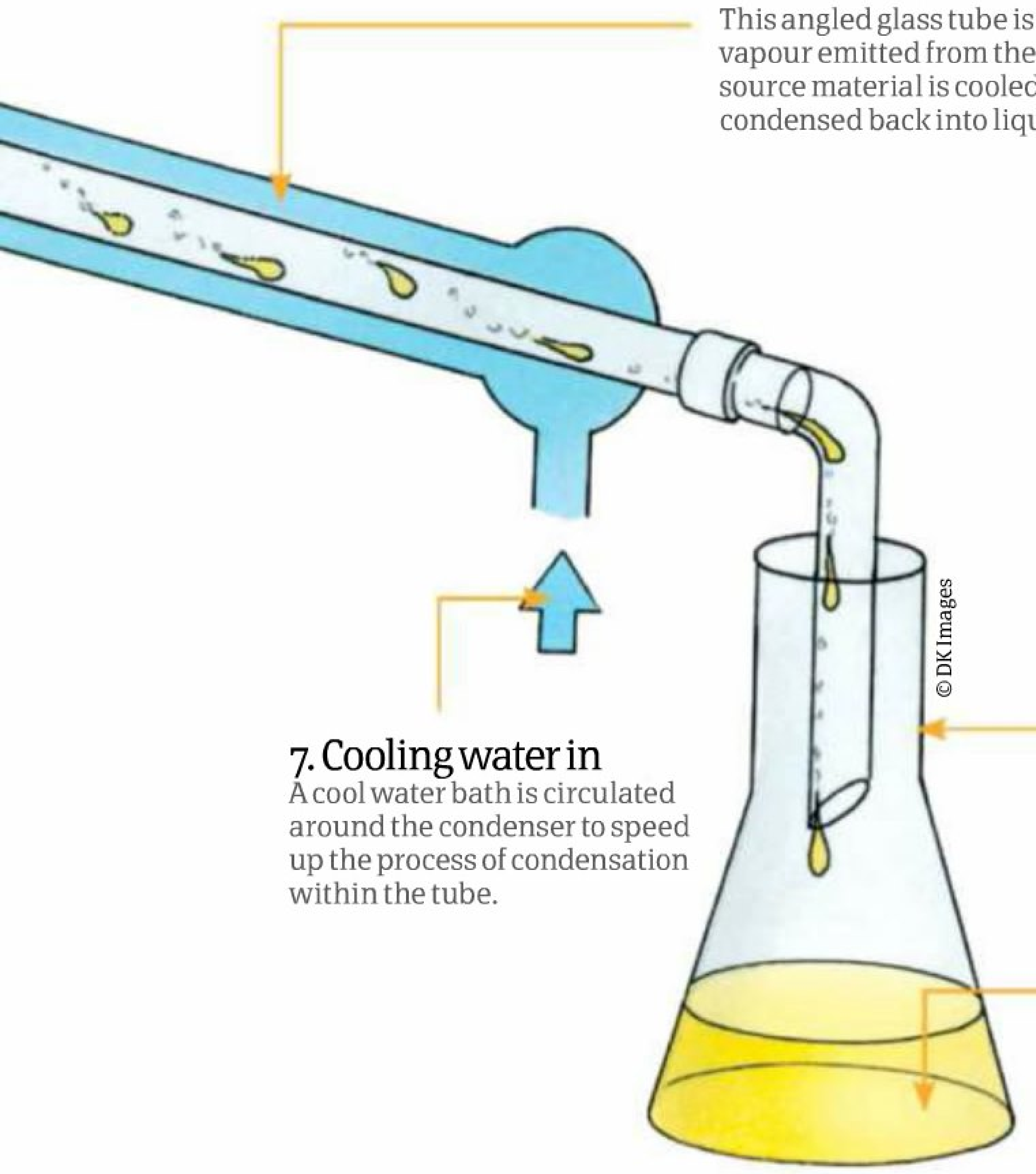
The alcohol found in wine, beer and hard liquor is really ethanol, the same stuff that powers alternative-fuel vehicles. To make ethanol (alcohol), all you need is a sugary (high carbohydrate) feedstock like grapes, corn or malted barley, plus water and yeast.

Yeasts are microscopic organisms that metabolise the carbohydrates in the feedstock and produce two by-products: ethanol and carbon dioxide. The carbon dioxide that is produced by yeast is what makes bread dough rise. To encourage ethanol production, brewers cover vats of fermenting material and allow only the carbon dioxide to escape.

Wine, beer and other fermented brews – like the grain mash that's used to make whisky – can be distilled to concentrate their alcohol content, creating more potent spirits like gin, vodka, brandy and rum.

Fractional distillation

In simple distillation, a single distillate is vaporised out of a solution and condensed in a single batch. Fractional distillation, meanwhile, is a technique for carefully separating multiple different components of a solution in a continuous process. The separation process occurs in a fractionating column that sits above the heated source material. The column is packed with tiny glass beads and contains multiple levels of condensing trays. An important characteristic of the fractionating column is that internal temperatures are hotter at the bottom and cooler at the top. As each component of the source material reaches its boiling point, it vaporises upward through the column. The components with the lowest boiling point rise higher in the column before cooling enough to condense back into liquid. The glass beads provide extra surface area to promote condensation, and the condensing trays collect each liquid component, which can then be siphoned out. Crude oil is separated into its useful by-products – eg kerosene, diesel fuel, natural gas and more – in towering fractionating columns.



© DK Images

6. Condenser
This angled glass tube is where vapour emitted from the source material is cooled and condensed back into liquid.

10. Receiving flask
The receptacle for the distillate is sometimes submerged in a water bath to speed up the cooling process.

7. Cooling water in
A cool water bath is circulated around the condenser to speed up the process of condensation within the tube.

9. Distillate
This is where the isolated component of the source material, called the distillate, is collected and cooled.

Simple distillation

How a single compound can be extracted from a mixed solution

© Arlen

5 uses of distillation

Distilled water

By boiling water and condensing its vapour, you achieve a purified water with lower levels of trace minerals and other impurities. Originally, distillation was used to make fresh drinking water from seawater, but now the purified liquid is used in car batteries and other chemical-electrical systems where the minerals found in tap water would disrupt the reaction.

Alcoholic spirits

© Anton Lecram

Beer and wine pack a pleasant alcoholic punch, but the alcohol content of such beverages is never more than 20 per cent by volume. Taking their cue from Arab alchemists, European brewers from the 14th Century distilled beer and wine to concentrate ethanol content, creating some of the more potent spirits like brandy and gin.

Oil refining

© Luigi Chiesa

The crude oil that we pump out of the ground is useless as a fuel. First, it must be refined through fractional distillation and separated into its component parts: diesel fuel, kerosene, gasoline and natural gas. Crude oil is heated to 600 degrees Celsius (1,112 degrees Fahrenheit) and its vapours ascend through a cooling column of air. As each component of crude oil reaches its boiling point, it condenses and flows out of the distillation column.

Separation of air

Air itself can be separated into its component elements – mainly nitrogen, oxygen and argon – via a process that is known as cryogenic distillation. In cryogenic distillation, gaseous air is first pressurised and then cooled to temperatures approaching -200 degrees Celsius (-328 degrees Fahrenheit), at which point its components condense and separate into purified liquid nitrogen, oxygen, argon and so on.

Perfume making

Persian alchemist Ibn Sina (aka Avicenna) is credited with first distilling essential oils to create rose water. Today, compounds come from flowers, herbs, resins and even some animal-based substances like ambergris, a musky grey lump that is regurgitated by sperm whales.

Why are bubbles spheres?

The skin of a bubble is composed of a thin layer of water molecules sandwiched between two layers of soap molecules. Water – on its own – has a high surface tension due to intermolecular forces. This causes molecules to pull on one another, trying to minimise the surface area and be as flat as possible. Soap reduces this surface tension. However the effect of surface tension is still present in a bubble which causes the bubble 'film' to be stretched. A sphere is formed because this shape is the shape with the least amount of surface area for its available volume.

Could scientists develop a way for humans to extract the oxygen from water in the future?

Oxygen can be extracted from water in a process known as electrolysis. Water molecules consist of two hydrogen atoms paired with one oxygen atom. Connecting two electrodes to a power supply and placing them into salted water allows an electric current to flow. Electricity is the flow of electrons, therefore one of the electrodes – the cathode – becomes negatively charged due to the buildup of electrons, while the other – the anode – becomes positively charged because of an electron deficit. This difference in charge causes water molecules to separate into their constituent parts, with oxygen bubbles appearing on the anode and hydrogen bubbles accumulating on the cathode.

This question could also be referring to whether we might one day be able to 'breathe' in the water. To do this, humans would need a system similar to fish gills in order to harness dissolved oxygen. All water in contact with the air will contain a small amount of dissolved oxygen – around five millilitres (0.01 pints) per litre (2.1 pints) – and it is this oxygen that diffuses into the bloodstream flowing through gills. It's impossible to know if humans could ever 'evolve' gills, however it is unlikely to serve any practical use since there is plenty of oxygen in the air.

“Human beings would need a system similar to fish gills in order to harness dissolved oxygen”

Why is glass transparent if it's in a solid state?

Shining light on a material bombards it with photons. Photons have a specific energy. What determines how photons interact with a material is their frequency, along with how the electrons in that material are arranged. Electrons can occupy different energy levels. In opaque materials, photons of visible light are mainly absorbed by electrons in the material. The electron then uses the photon's energy to jump to a higher energy state. With glass, the amount of energy needed to raise an electron to the next energy level is higher than most materials and the photons of visible light do not have enough energy to bridge this gap, so the photons pass through.

Why do irons work so much better when they are hot?

Cloth fibres are bound together by chemical bonds. The polymer strands becoming fixed in unnatural shapes (wrinkles) as the fabric bends. These bonds are weakened by heat, so when a hot iron is applied, the cross-linking between the fibres is loosened, allowing the weight of the iron to force them into a flatter shape. When the heat is removed, the polymers re-bind into their new position and form a freshly pressed shirt, skirt or pillowcase. Weight without heat makes the job much harder unless water is added. Hence the wrinkle-busting power of the steam iron.

Why do we shiver when we're cold?

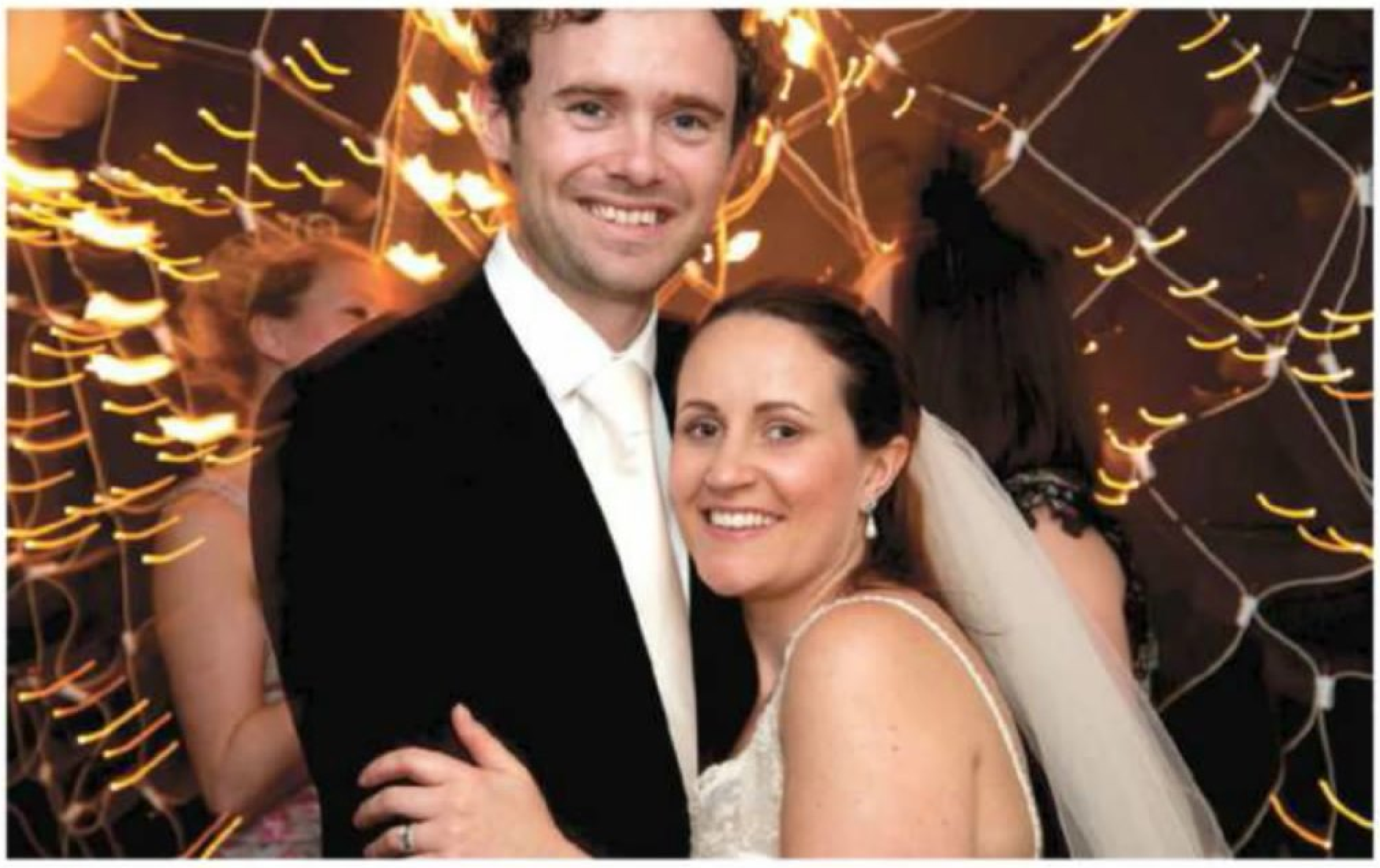
Shivering is actually an evolved response to keep us alive. If the temperature of our internal organs falls much below 37 degrees Celsius (99 degrees Fahrenheit), we could die of hypothermia. When the brain detects that we are cold enough that this might happen, it stimulates muscles to jiggle slightly. In moderately low temperatures this creates enough heat to keep our organs from slowing down, also making us tremble. Shivering consumes energy and only works when it isn't extremely cold.

Why does coffee give some people headaches?

Caffeine, the prime ingredient in coffee, is a common stimulant that acts on the central nervous system. Most people know that caffeine comes in tea, coffee, some fizzy drinks and chocolate. However, what most people don't know is that it's in many medicines too. It's also sold in stimulant tablets that some people take to stay awake. Caffeine can both cause and relieve headaches. When in medications, it acts to improve absorption of the other substances in the product, while also causing blood vessels in the brain to constrict slightly, which can relieve headaches caused by dilated veins (eg migraines). However caffeine can also cause headaches; in fact, it's the caffeine withdrawal that causes the pain. Since caffeine normally induces vasoconstriction of the blood vessels in the brain, a sudden lack of it leads to vasodilation (ie the blood vessels swell). This can give a 'pounding' headache, which is relieved as soon as you have some caffeine. It's not just the heavy coffee drinkers who get this; some people can become 'addicted' to very small amounts of daily caffeine.

What causes the 'butterflies in my stomach' feeling?

I've got butterflies in my stomach – this relates to more than just that feeling you get when you're around someone you'd like to kiss, as the same feeling also comes when you're nervous (eg before an exam or the first day on a new job). These feelings are most likely related to the fight or flight reflex. When something stressful is about to happen (in evolution this would be fighting a predator/rival), the body switches into an 'action mode', which sends adrenaline speeding through your bloodstream. In addition, the autonomic nervous system diverts blood away from non-essential systems (such as your stomach and intestines) and sends it to the muscles and brain. The vagus nerve, which is a key mediator of this effect, slows stomach function, as well as increasing the heart rate. This may be the reason that your stomach, which doesn't need to be active during these situations, reports a different sensation to your brain. Now the next time you hear someone say they have butterflies in their tummy, you know exactly why that's happening.



If you jump up on a moving plane, why don't you land farther up the aisle than where you leapt from?

If you jump straight up on a moving plane you will land on the same spot you initially jumped from because the air – and indeed everything else inside the craft – is moving at the same speed as the plane. If it were possible for a stationary observer outside to see you jump, they would witness you moving forward through the air at the same speed as the aeroplane during your leap. Of course, this assumes the plane is moving at a constant speed. If you were to attempt a jump while the aircraft was speeding up or slowing down – and we're certainly not recommending you do – you wouldn't land in the same spot.

Why does ice cream that has melted and refrozen often have ice crystals?

Ice cream is usually made from milk (which contains water, lipids, proteins and lactose), flavourings and sugar. Separate ice crystals are always present in ice cream. However they are so small and numerous that our tongues can't detect them. Ice cream gets its smooth texture in the manufacturing process by being stirred slowly while cooling. Larger ice crystals will form upon refreezing melted ice cream due to the preference of water droplets to join together, and thus form bigger droplets. Mixing while refreezing would help keep the droplets as small as possible, however you should never return thawed ice cream to the freezer anyway as this is a health risk.

Why is reheating rice bad for you?

It's all in how you cooked and handled the rice. Rice naturally contains the spores of a bacterium called bacillus cereus. If you cook rice correctly, then store it in a calibrated refrigerator within two hours, you have nothing to fear. The problem comes when cooked rice is kept at an unsafe temperature for a long period of time as this allows the spores to breed. No amount of reheating after that can kill them, and eating the rice can cause diarrhoea and vomiting. Any food cooked and stored improperly can make you sick, but many people don't know rice is a potential culprit.

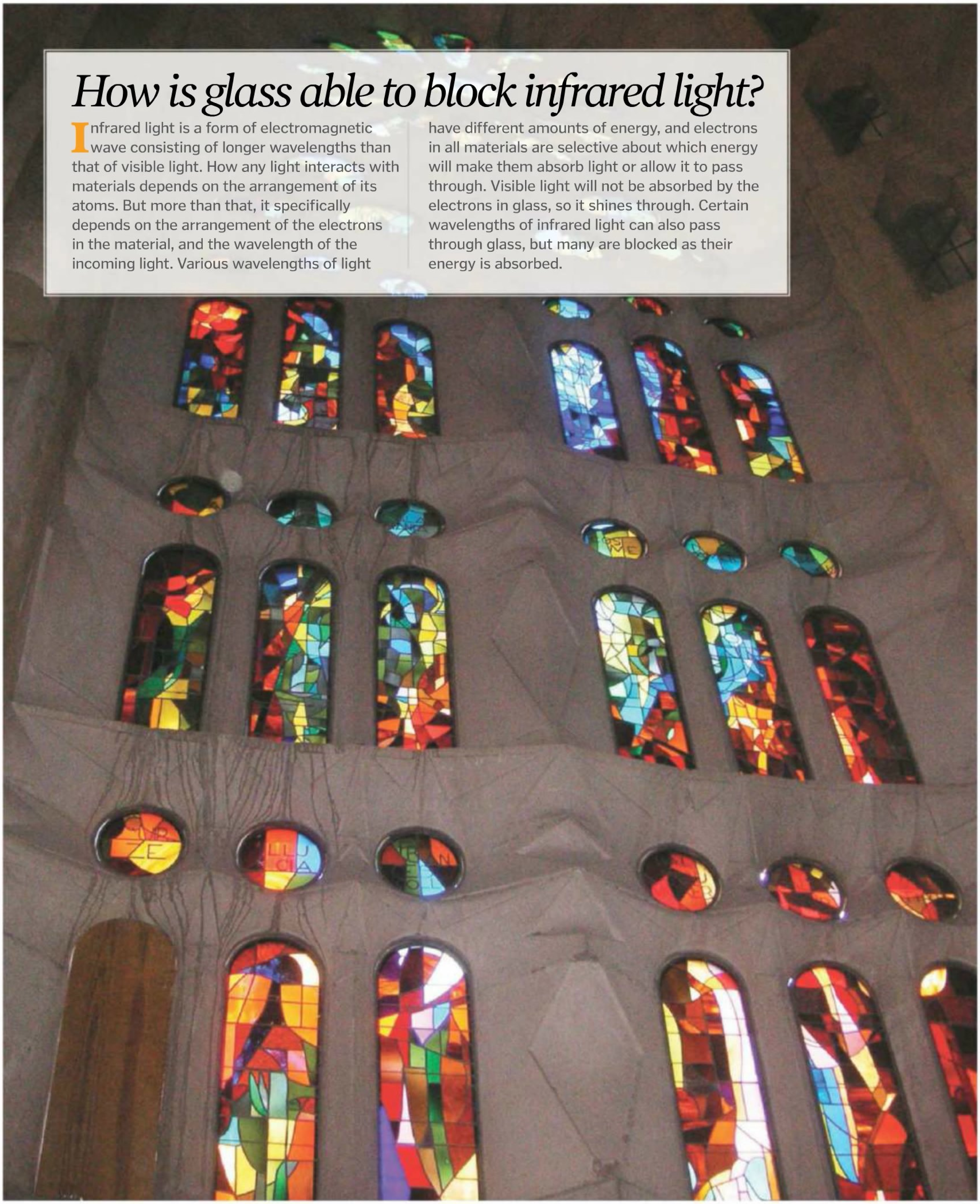
If we're constantly shedding our skin, how much do we lose over a lifetime?

Skin is our body's largest organ – on average an adult has about two square metres (22 square feet) of it, or in weight about 3.6 kilograms (eight pounds).

It protects our internal organs, produces vitamins and minerals, provides tactile feedback, and helps us retain water; that's why keeping it moisturised and well protected is so important. Because of all this, skin constantly needs to reproduce itself. For each minute that goes by, you've shed 40,000 skin cells, and your skin is renewed every 35 or so days. So if you live for 80 years, you'll have renewed your skin around 800 times, shedding up to 2,880 kilograms (6,400 pounds).

How is glass able to block infrared light?

Infrared light is a form of electromagnetic wave consisting of longer wavelengths than that of visible light. How any light interacts with materials depends on the arrangement of its atoms. But more than that, it specifically depends on the arrangement of the electrons in the material, and the wavelength of the incoming light. Various wavelengths of light have different amounts of energy, and electrons in all materials are selective about which energy will make them absorb light or allow it to pass through. Visible light will not be absorbed by the electrons in glass, so it shines through. Certain wavelengths of infrared light can also pass through glass, but many are blocked as their energy is absorbed.



Environment

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How does the Arctic Ocean freeze?

It's difficult to imagine such a huge expanse of water freezing solid, so how is it possible?

Arctic sea ice is that which forms on the Arctic Ocean during the winter months. Pure water, which contains no other molecules, substances or impurities, freezes at 0 degrees Celsius (32 degrees Fahrenheit). The world's seawater, on the other hand, contains around 3.5 per cent dissolved minerals and salts. This additional material lowers the freezing point of the seawater to around -2 degrees Celsius (28.4 degrees Fahrenheit) because the freezing point depends on the number of molecules present in a solution, as well as the type of molecule(s).

During the winter months, when the air temperature in the Arctic starts to fall dramatically, a deep layer of seawater begins to develop minuscule ice crystals; this slushy water is called frazil ice. A further drop in temperature causes the frazil ice to thicken. Pockets of salty slush accumulate until they become so heavy they start to sink. This leaves the top layer of icy crystals with significantly less salt content. The freezing point of this surface water therefore becomes higher and the falling temperatures enable the crystals to solidify into pack ice.

This pack ice grows to become one huge floating sheet (made up of many smaller floes), the thickness and coverage of which varies over the year, but reaches its peak in March. During the warmer summer months, meanwhile, the ice begins to retreat and break up, reaching its lowest extent around September.

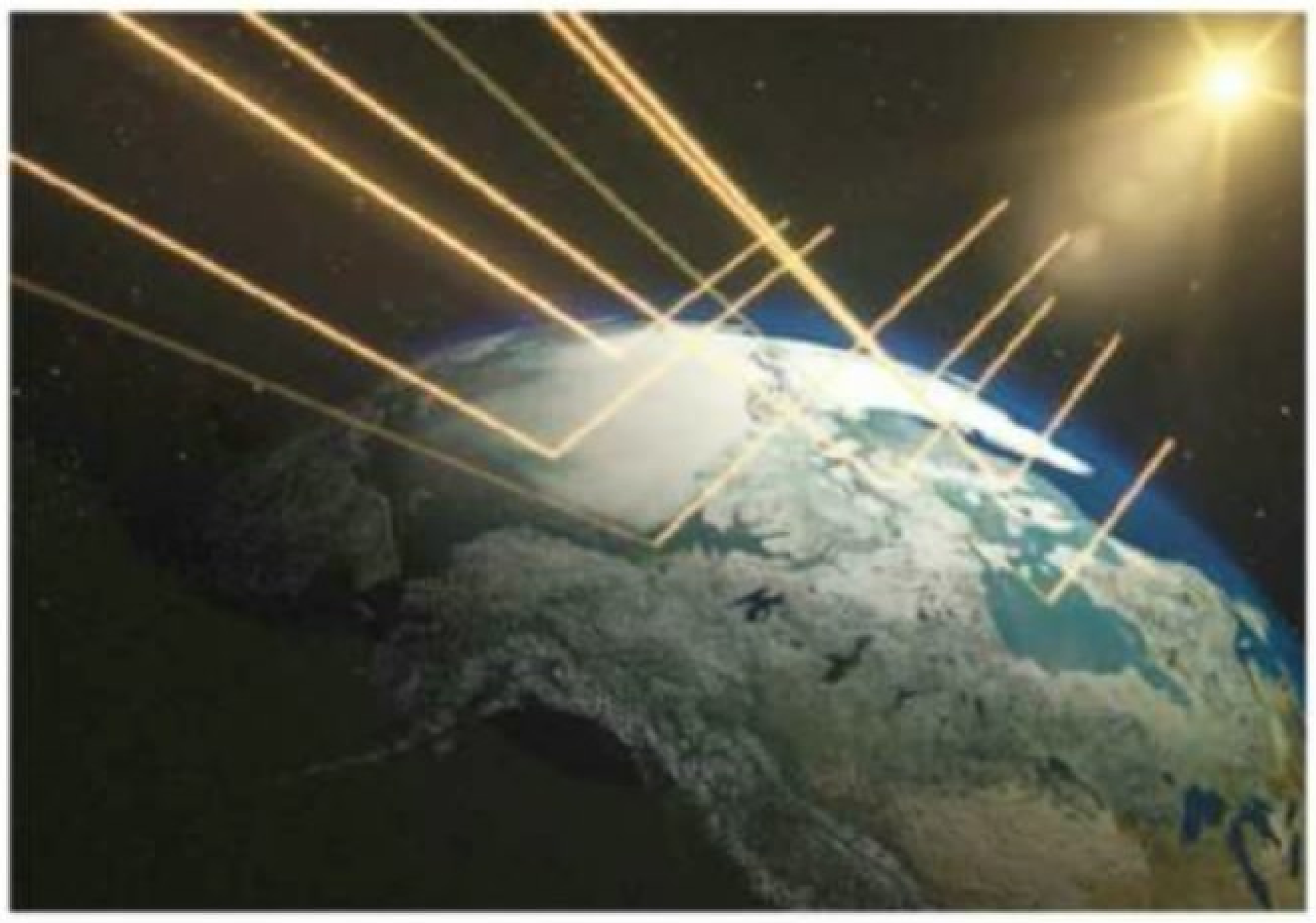
Understanding how polar ice affects the world climate

Sea ice at the poles is important because it influences the weather across the entire planet. The ice acts like a mirror, deflecting the Sun's rays back into the atmosphere. As the ice melts, more of the 'dark' ocean beneath, capable of absorbing the Sun's heat, is exposed.

When the Arctic is frozen, warmer water entering from the Pacific or Atlantic begins to cool, becoming dense and sinking. This displacement of water drives the circulation of Earth's oceans, affecting weather and conditions throughout the world. So, in many respects, the amount and extent of Arctic sea ice is absolutely critical to the global climate.

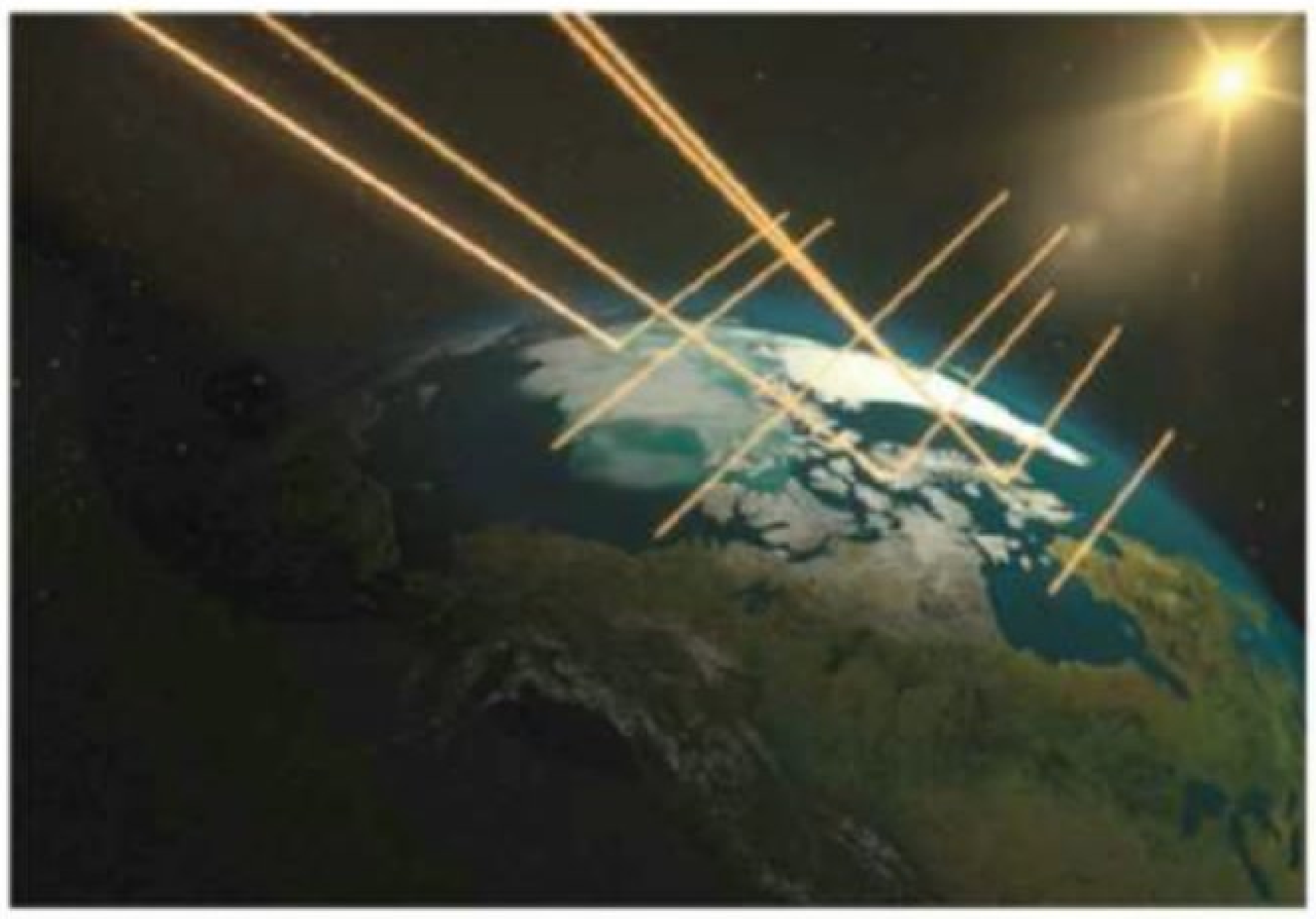
A satellite shot of sea ice floes and icebergs off the coast of Antarctica

© SPL



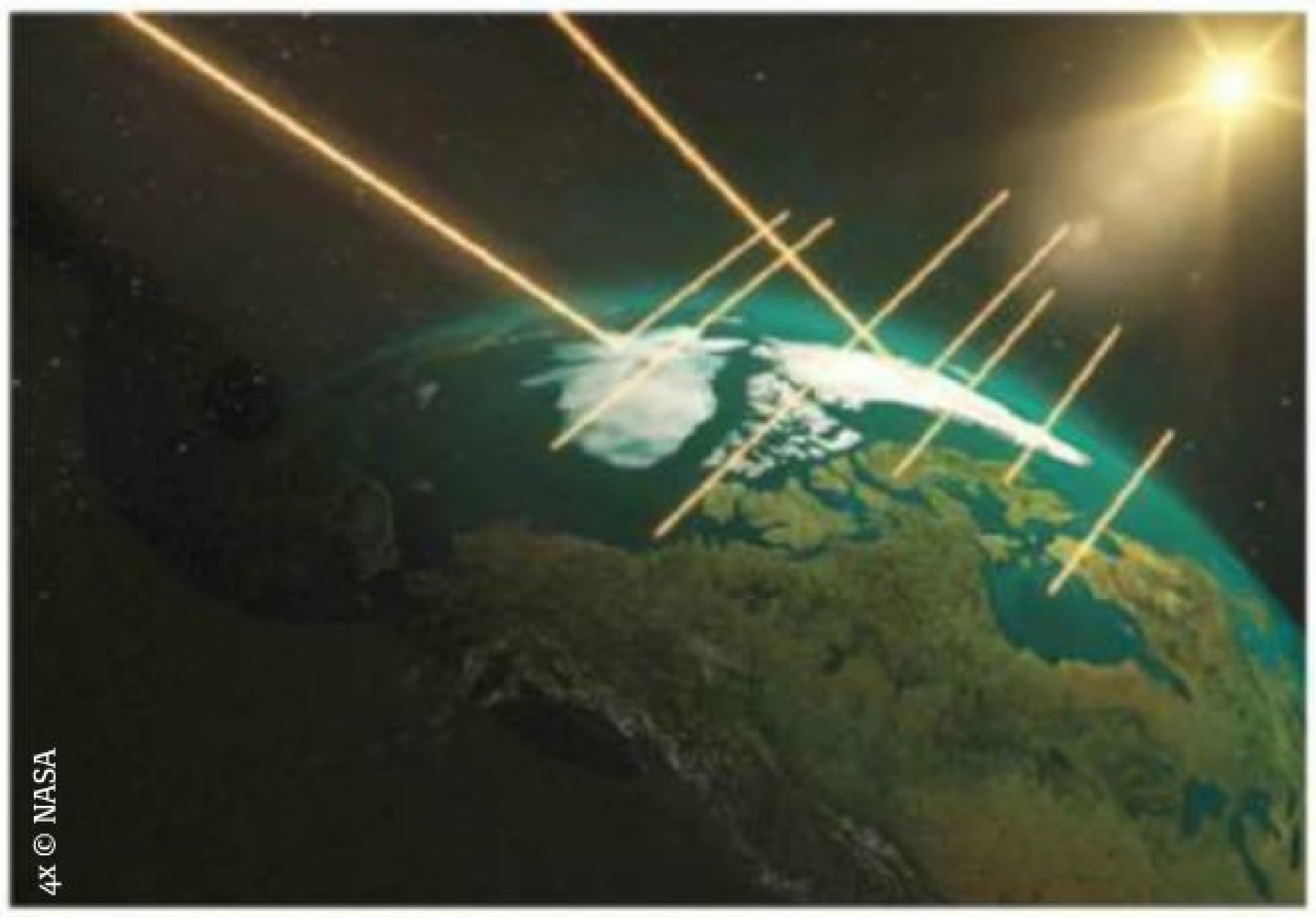
High reflection

The white sea ice cover acts like a mirror, reflecting the Sun's rays back out to space, preventing the sea from heating excessively.



Sea exposed

As the ice melts, there is more dark seawater to absorb sunlight, which further melts the ice.



4x © NASA

Low reflection

The more sunlight absorbed by the seawater, the more the ice melts until, eventually, significantly less light is reflected back into space.

What causes red tides?

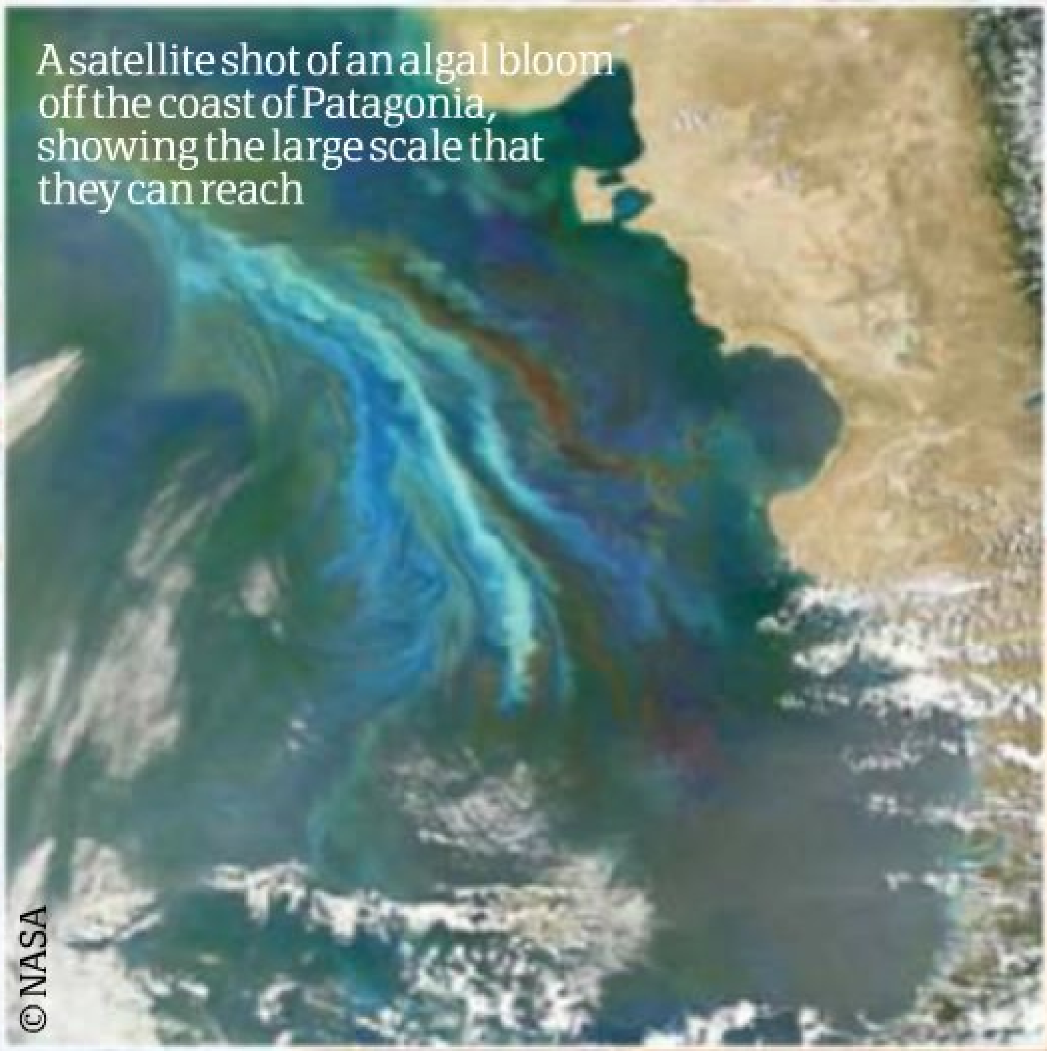
Why crimson seas are not as unbelievable a sight as you might first think…

A red tide is the rapid accumulation of a mass of aquatic algae made up of mobile single-celled micro-organisms known as dinoflagellates – which means 'whirling whip' due to the nature of the tail-like projections that propel them through the water. The algae grows, or blooms, more rapidly than usual in order to consume nutrients that have suddenly risen up from the colder depths of the ocean below. The red hue is down to the presence of a certain species of dinoflagellate, or phytoplankton.

Together with the more abundant diatom algae, dinoflagellates make up the majority of ocean plankton. Despite the rather startling appearance of a sea that has been turned red, many algal blooms are actually completely harmless. However, you shouldn't consume seafood following a red tide as certain phytoplankton can release harmful substances into the water. Some dinoflagellates can produce toxins when eaten by other creatures and the harmful substances then concentrate inside the creatures that feed on them, and subsequently any humans who go on to dine on the contaminated seafood.

The billions of microscopic dinoflagellates in a red tide can also cause spectacular bioluminescence at night. One species in particular – the lingulodinium polyedrum – can create its own light from within. When the organism is jostled or collides with something in the ocean, a chemical reaction occurs when an enzyme called luciferase and a substrate called luciferin, both contained within the organism, combine. This is the catalyst for a chemical reaction that releases a flash of blue light. When this occurs millions of times simultaneously, the effect is quite remarkable for onlookers.

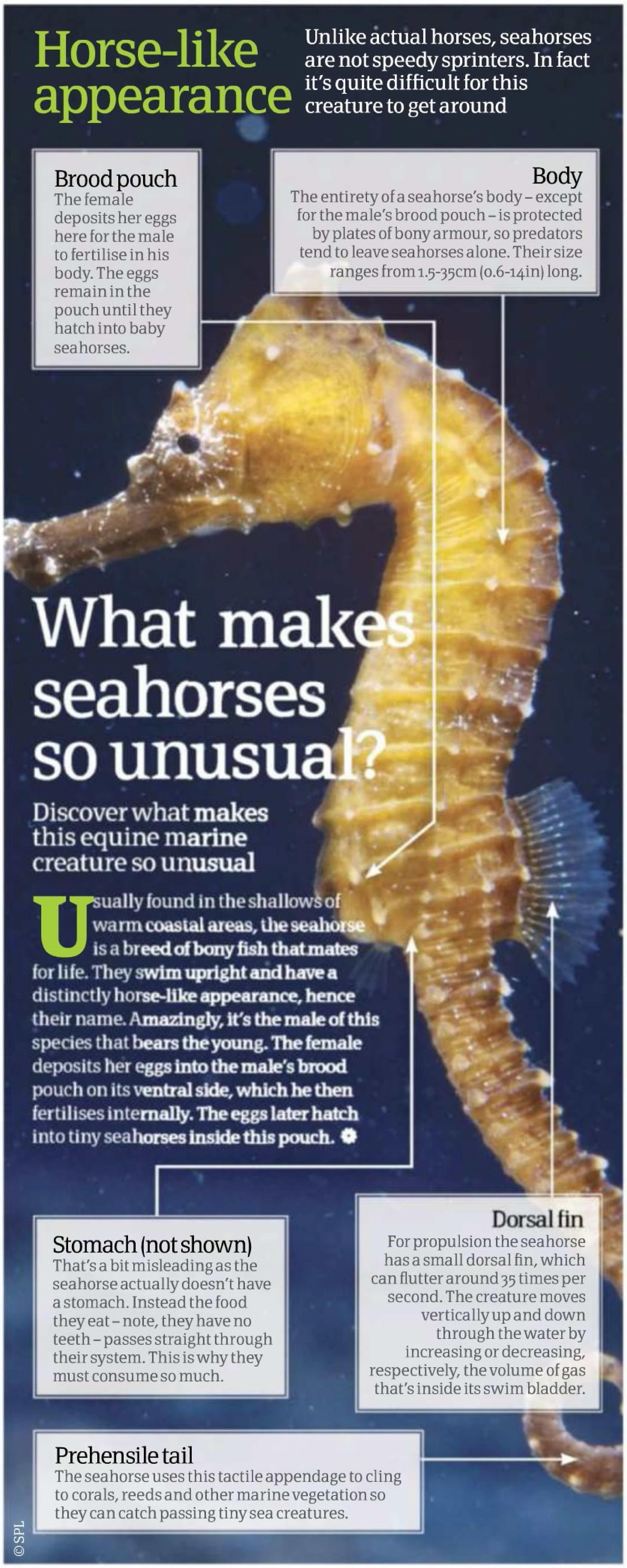
> "Despite the startling appearance of a sea turned red, many algal blooms are actually harmless"



A satellite shot of an algal bloom off the coast of Patagonia, showing the large scale that they can reach

© NASA

2x © SPL



What makes seahorses so unusual?

Discover what makes this equine marine creature so unusual

Usually found in the shallows of warm coastal areas, the seahorse is a breed of bony fish that mates for life. They swim upright and have a distinctly horse-like appearance, hence their name. Amazingly, it's the male of this species that bears the young. The female deposits her eggs into the male's brood pouch on its ventral side, which he then fertilises internally. The eggs later hatch into tiny seahorses inside this pouch.

Horse-like appearance

Unlike actual horses, seahorses are not speedy sprinters. In fact it's quite difficult for this creature to get around

Brood pouch
The female deposits her eggs here for the male to fertilise in his body. The eggs remain in the pouch until they hatch into baby seahorses.

Body
The entirety of a seahorse's body – except for the male's brood pouch – is protected by plates of bony armour, so predators tend to leave seahorses alone. Their size ranges from 1.5-35cm (0.6-14in) long.

Stomach (not shown)
That's a bit misleading as the seahorse actually doesn't have a stomach. Instead the food they eat – note, they have no teeth – passes straight through their system. This is why they must consume so much.

Dorsal fin
For propulsion the seahorse has a small dorsal fin, which can flutter around 35 times per second. The creature moves vertically up and down through the water by increasing or decreasing, respectively, the volume of gas that's inside its swim bladder.

Prehensile tail
The seahorse uses this tactile appendage to cling to corals, reeds and other marine vegetation so they can catch passing tiny sea creatures.

© SPL.

How do pearls form?

How does a speck of dirt turn into a precious gem?

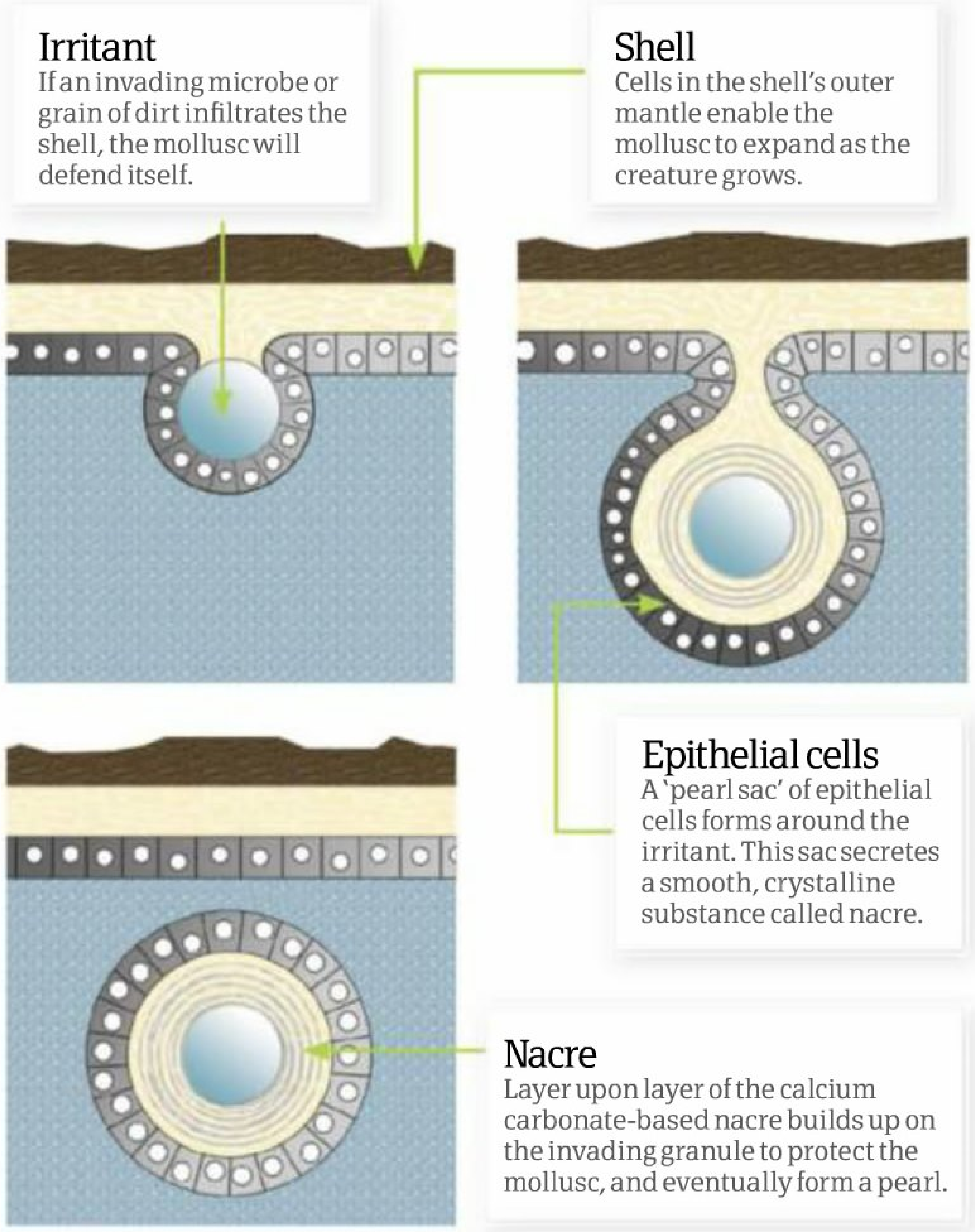
Pearls develop inside molluscs – including oysters, mussels and clams – whenever a foreign particle enters its shell and irritates the soft inner tissues. If the animal can't immediately expel the irritant, it will engage a unique defence mechanism.

To protect itself from the tiny particle, the mollusc produces a substance called nacre, or mother-of-pearl, which also lines the inner surface of the creature's shell. Layer upon layer of the hard crystalline nacre is then used to smother the invading object so it cannot harm or contaminate the mollusc.

A pearl's iridescent appearance is due to the many layers of nacre that consist of many microscopic crystals. The thickness of one layer of calcium carbonate plates is similar to the wavelength of visible light. Some of the light passing through the top layer of nacre will be reflected, but some will continue to travel through to the bottom layer where further light is reflected. Multiple reflections interfere with each other at different wavelengths, causing colours to be reflected and scattered in all directions, creating an iridescent finish. This is a phenomenon that not even science can replicate.

Creating a pearl

How a tiny foreign body transforms into a lustrous gemstone

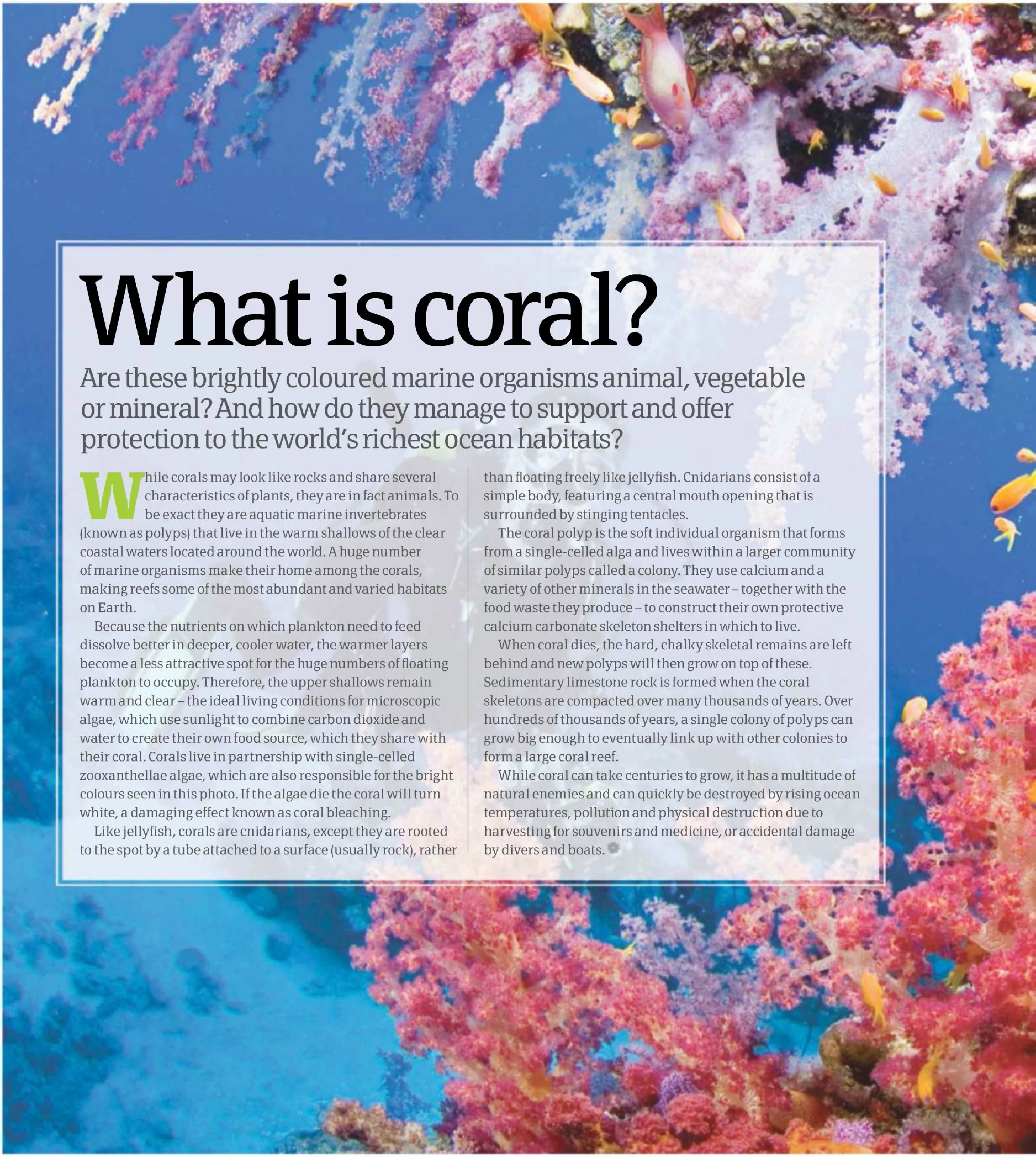


Irritant
If an invading microbe or grain of dirt infiltrates the shell, the mollusc will defend itself.

Shell
Cells in the shell's outer mantle enable the mollusc to expand as the creature grows.

Epithelial cells
A 'pearl sac' of epithelial cells forms around the irritant. This sac secretes a smooth, crystalline substance called nacre.

Nacre
Layer upon layer of the calcium carbonate-based nacre builds up on the invading granule to protect the mollusc, and eventually form a pearl.



What is coral?

Are these brightly coloured marine organisms animal, vegetable or mineral? And how do they manage to support and offer protection to the world's richest ocean habitats?

While corals may look like rocks and share several characteristics of plants, they are in fact animals. To be exact they are aquatic marine invertebrates (known as polyps) that live in the warm shallows of the clear coastal waters located around the world. A huge number of marine organisms make their home among the corals, making reefs some of the most abundant and varied habitats on Earth.

Because the nutrients on which plankton need to feed dissolve better in deeper, cooler water, the warmer layers become a less attractive spot for the huge numbers of floating plankton to occupy. Therefore, the upper shallows remain warm and clear – the ideal living conditions for microscopic algae, which use sunlight to combine carbon dioxide and water to create their own food source, which they share with their coral. Corals live in partnership with single-celled zooxanthellae algae, which are also responsible for the bright colours seen in this photo. If the algae die the coral will turn white, a damaging effect known as coral bleaching.

Like jellyfish, corals are cnidarians, except they are rooted to the spot by a tube attached to a surface (usually rock), rather than floating freely like jellyfish. Cnidarians consist of a simple body, featuring a central mouth opening that is surrounded by stinging tentacles.

The coral polyp is the soft individual organism that forms from a single-celled alga and lives within a larger community of similar polyps called a colony. They use calcium and a variety of other minerals in the seawater – together with the food waste they produce – to construct their own protective calcium carbonate skeleton shelters in which to live.

When coral dies, the hard, chalky skeletal remains are left behind and new polyps will then grow on top of these. Sedimentary limestone rock is formed when the coral skeletons are compacted over many thousands of years. Over hundreds of thousands of years, a single colony of polyps can grow big enough to eventually link up with other colonies to form a large coral reef.

While coral can take centuries to grow, it has a multitude of natural enemies and can quickly be destroyed by rising ocean temperatures, pollution and physical destruction due to harvesting for souvenirs and medicine, or accidental damage by divers and boats.

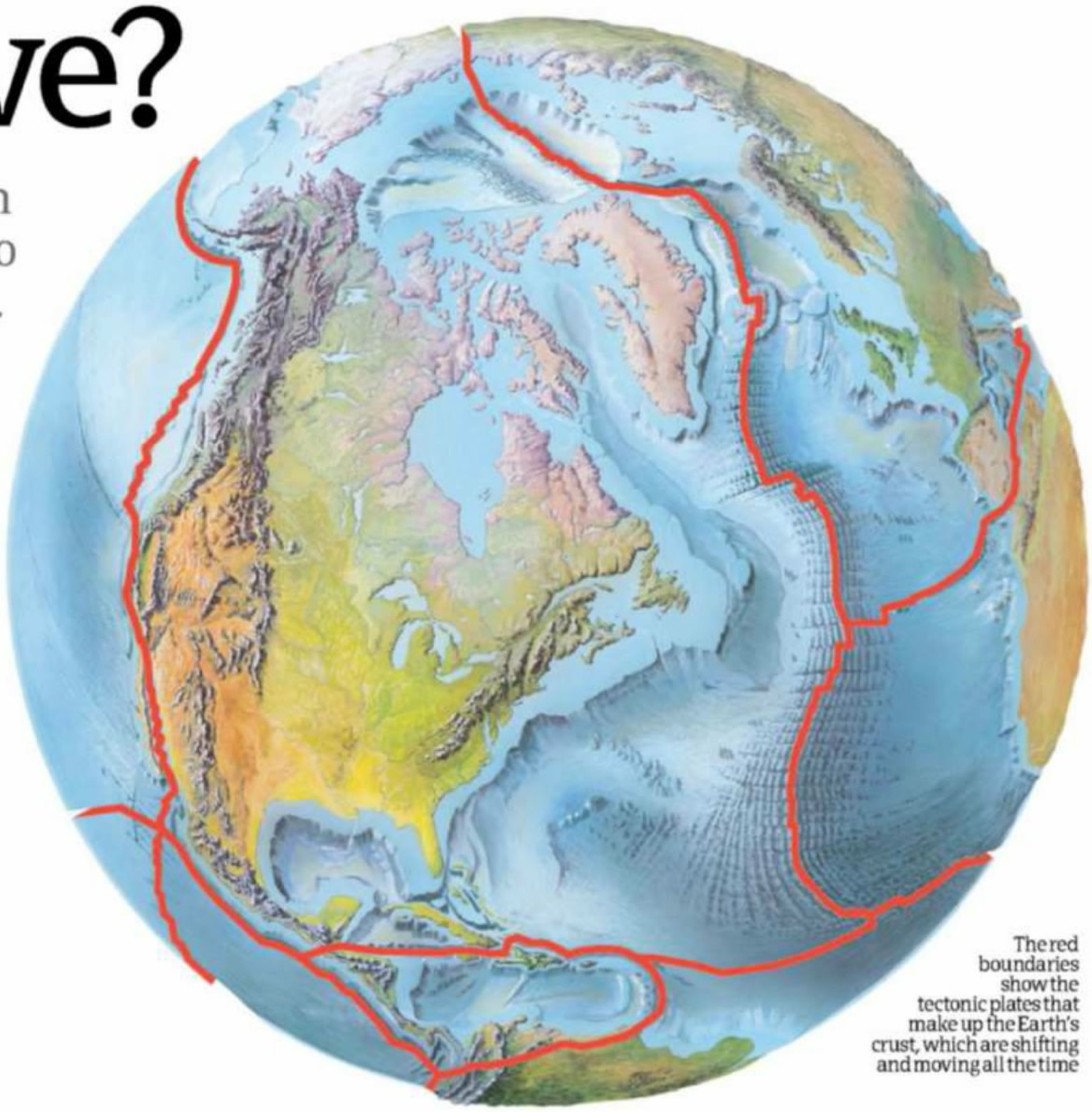
What makes marine mountains so massive?

If you thought mountain ranges were restricted to land, then think again…

The Mid-Atlantic Ridge is part of the longest mountain range in the world – these mountains just happen to be underwater. Mid-ocean ridges are a result of plate tectonics, and form due to volcanic activity in the oceanic crust. Currents in the Earth's mantle cause magma to heat up, and it is forced through weak spots in the crust. The resulting lava cools into a new layer of crust. This pushes the plates apart and the resulting formation often has a rift, or valley, in the centre where two different plates are being pushed apart. All of these mid-ocean ridges are connected around the world, totalling 80,000 kilometres (50,000 miles) or so in length.

The Mid-Atlantic Ridge by itself is around 10,000 kilometres (6,200 miles) long. It separates the North American tectonic plate (which also includes the Bahamas, Cuba, Greenland and parts of other countries) from the Eurasian tectonic plate. On top of that, it separates the South American tectonic plate from the African tectonic plate. Most of the mid-Atlantic plate is underwater, but some of it is actually high enough to appear above sea level. This includes a ridge that contains the island of Iceland, as well as a number of other small islands.

Oceanographers and researchers have thought there was a mountain range in the ocean here since the 1870s, and it was confirmed in 1925 by sonar. It wasn't until the Fifties, however, that we were able to fully understand the unique features hidden in the depths of the mid-Atlantic, and realised just how massive it really was. In addition to the islands, there are numerous deep trenches and valleys as well as extensive seismic activity, which is constantly altering the terrain.



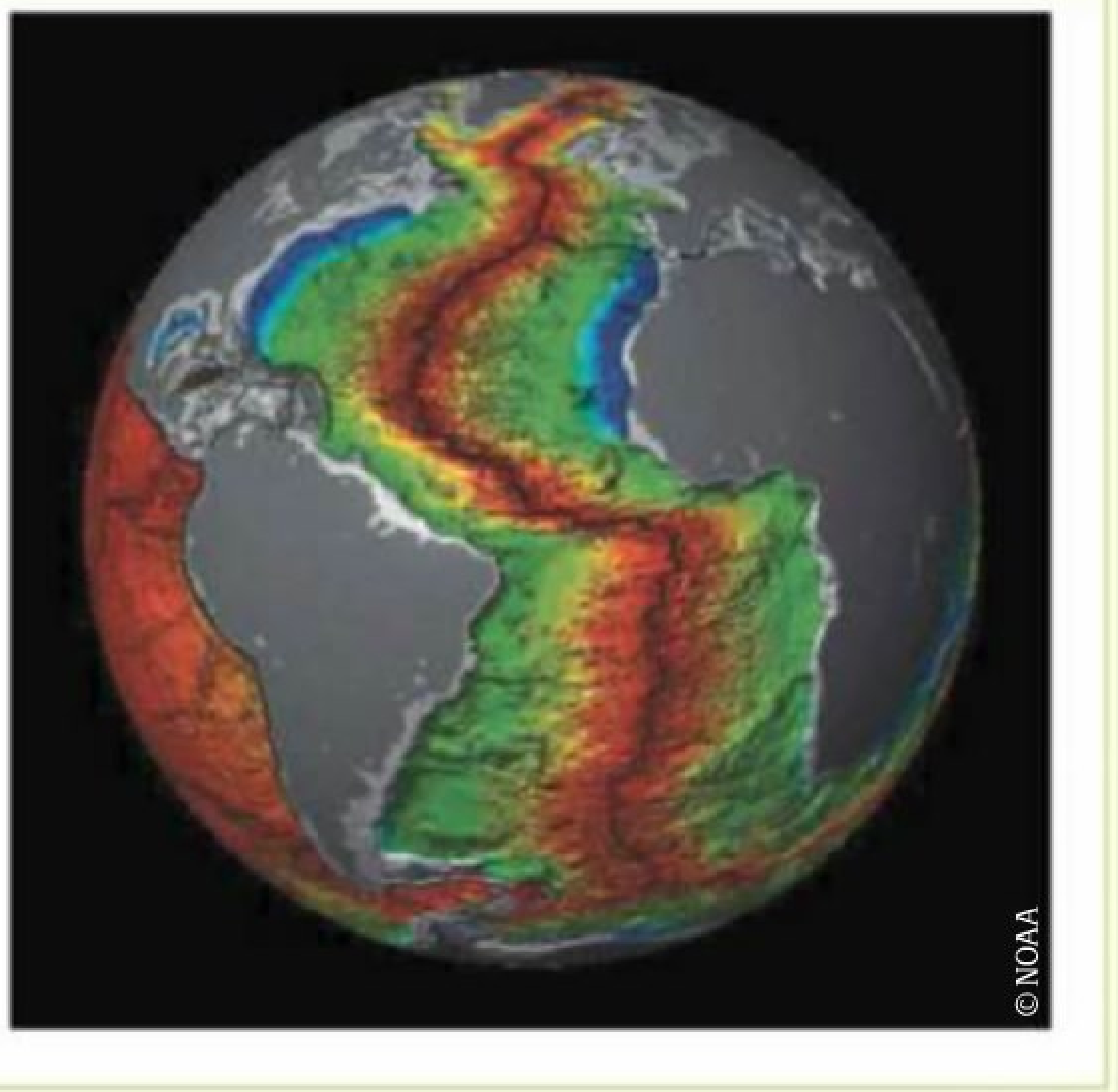
The red boundaries show the tectonic plates that make up the Earth's crust, which are shifting and moving all the time

What lies beneath…

The Mid-Atlantic Ridge actually sits on another formation in the ocean, which is called the Mid-Atlantic Rise. This elevation is a sort of bulge off the ocean floor, which is caused by immense pressure in the mantle pushing up through the crust.

The Mid-Atlantic Rise is thought to have formed during the Triassic period, dating back to about 200 million years ago. The central valley of the Mid-Atlantic Ridge experiences a lot of earthquakes as well, which is probably also due to the instability in the mantle.

Because of the continual seismic and volcanic activity the ocean floor here is slowly but consistently spreading along the ridge at a rate of 2.5 centimetres (one inch) per year.



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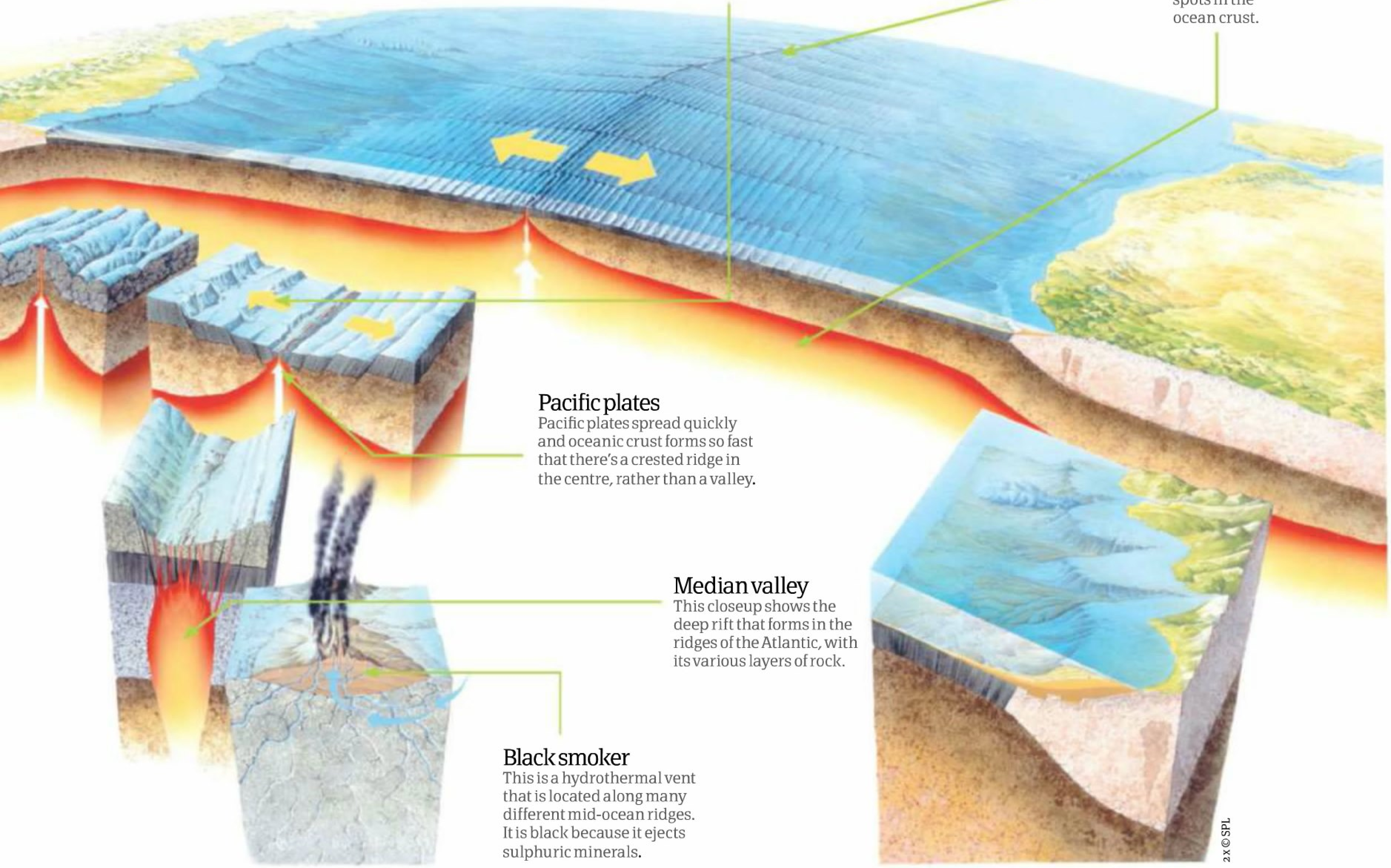
Seafloor evolution

The terrain of the ocean floor is changing all the time due to the ongoing activity…



Atlantic plates
Atlantic plates are slow spreading, which results in a deep valley forming between the plates.

Lava
Lava cools in the ocean and builds up in a ridge.

Molten rock
Magma rises up through weaker spots in the ocean crust.

Pacific plates
Pacific plates spread quickly and oceanic crust forms so fast that there's a crested ridge in the centre, rather than a valley.

Median valley
This closeup shows the deep rift that forms in the ridges of the Atlantic, with its various layers of rock.

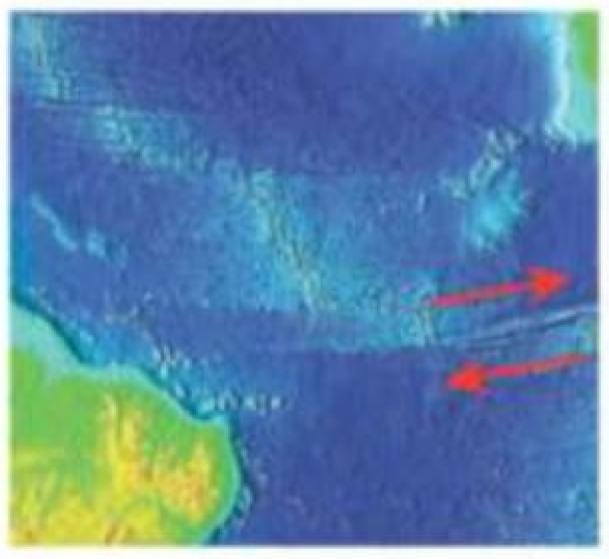
Black smoker
This is a hydrothermal vent that is located along many different mid-ocean ridges. It is black because it ejects sulphuric minerals.

2 x © SPL

Mid-Atlantic Ridge key features

Romanche Trench

This trench is the third deepest in the Atlantic, and bisects the Mid-Atlantic Ridge around the equator. It's about 19km (12mi) wide, 300km (186mi) long and 7.76km (4.82mi) deep. It plays a key role in water circulation between the east and west Atlantic basins.

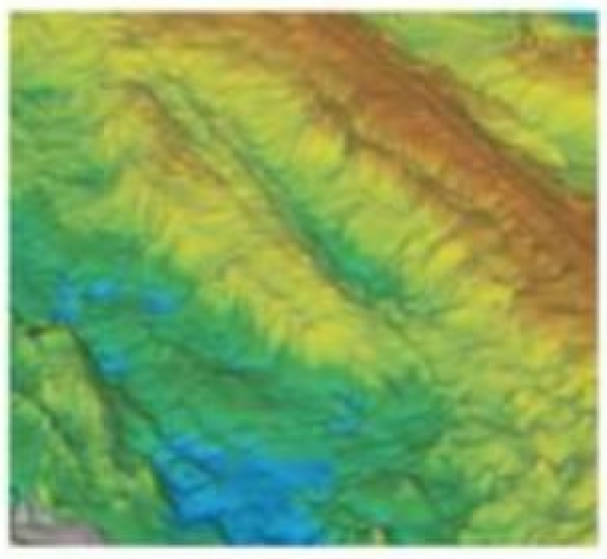


Iceland

Iceland is part of a sub-ridge on the Mid-Atlantic Ridge that's known as the Reykjanes Ridge; this rises 2,110m (6,923ft) from the seabed. Iceland is also on top of a mantle plume, a place where hot rock has risen through the mantle but isn't a part of plate tectonics.

Deep rift valley

This valley runs the entire length of the Mid-Atlantic Ridge and serves as the boundary between the North American and the Eurasian tectonic plates that are separated by the ridge. At 1-3km (0.6-1.8mi) deep, it is similar in depth to the Grand Canyon.



Atlantis Massif

This hill is just west of the centre of the ridge. It's about 1,700m (5,500ft) high and much wider than other hills on the ocean floor. It's smooth compared to the surrounding terrain, and oceanographers are still trying to determine how it formed.

© NOAA

Hydrothermal vents

These vents are located in the same region as the Atlantis Massif. They're openings in the crust where geothermally heated water spews into the ocean. They vent a lot of methane and hydrogen into the water, and this has created a unique ecosystem.

How was the Giant's Causeway formed?

Discover the origins of this geological phenomenon in Northern Ireland which consists of around 38,000 basaltic columns

© SPL

On the north-east coast of County Antrim in Northern Ireland lies an unusual rock formation which draws in millions of visitors from around the world every year. They flock to see a vast plateau of polygonal basalt columns – which are commonly known as the Giant's Causeway – which looks like a carpet of enormous stepping stones extending out into the Irish Sea. The basalt pillars that make up this amazing rock formation dramatically range in size from a matter of centimetres to several metres high.

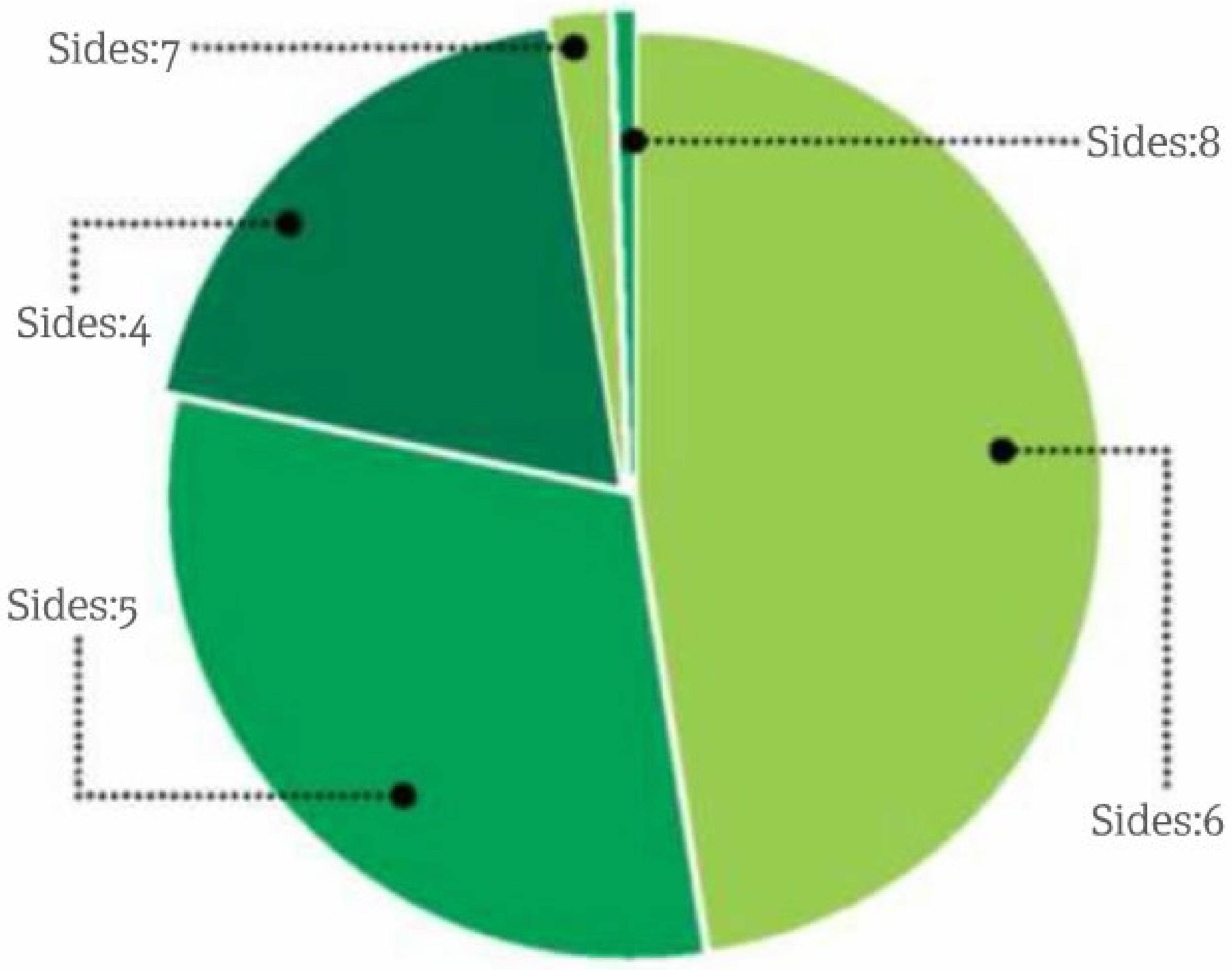
Although the Giant's Causeway is so-named due to an ancient legend, its formation actually began up to 65 million years ago during the Tertiary period when volcanic activity forced tectonic plates to stretch and break. This caused magma to spew up from inside the Earth and spill out across the surface as lava.

The temperature of erupting lava can range from between 700 and 1,200 degrees Celsius (1,292 and 2,192 degrees Fahrenheit). However, upon contact with the surface it will immediately begin to cool. At first this cooling is extremely rapid and this results in a hardened crust forming on top of the superhot substance, which insulates the still liquid lava below. Because the lava is now insulated the cooling becomes increasingly slow over time. While you could probably walk on the crust after just half an hour or so, thick lava flows can take a number of years to cool completely and solidify all the way through.

While the temperature falls the lava begins to dry out, and it's this drying that causes the solidifying lava to crack and form regular pillars of basalt rock. The size and shape of each column is ultimately determined by the rate at which the lava actually cools and dries, and therefore the speed at which what's called the 'drying front' moves. Scientists from the University of Toronto discovered that the slower the cooling rate the larger the basalt columns that formed.

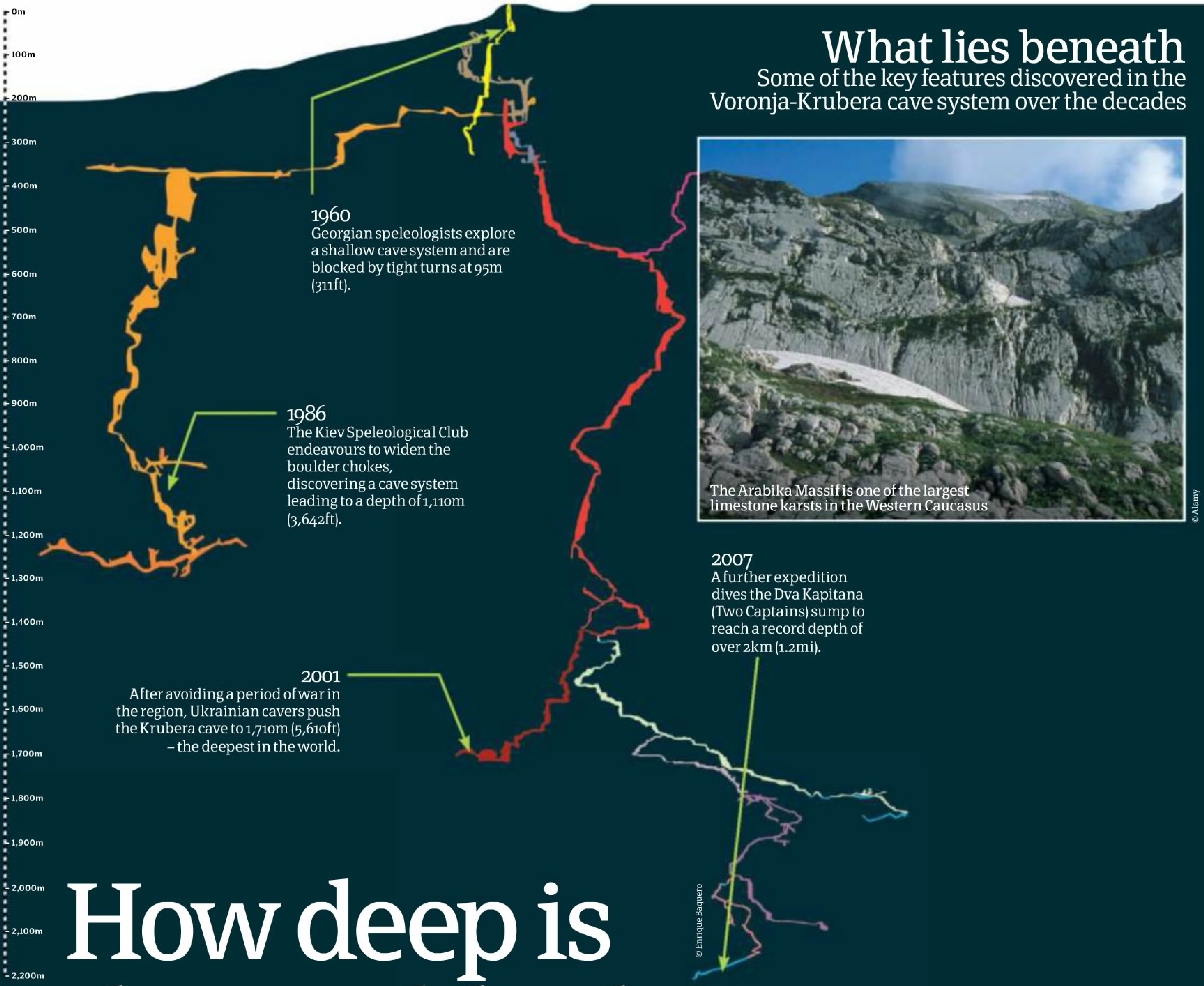
Polygonal pillars of rock

Though the number of sides to each pillar varies, of the 38,000 basalt columns the majority are hexagonal



What lies beneath

Some of the key features discovered in the Voronja-Krubera cave system over the decades



1960
Georgian speleologists explore a shallow cave system and are blocked by tight turns at 95m (311ft).

1986
The Kiev Speleological Club endeavours to widen the boulder chokes, discovering a cave system leading to a depth of 1,110m (3,642ft).

2001
After avoiding a period of war in the region, Ukrainian cavers push the Krubera cave to 1,710m (5,610ft) – the deepest in the world.

2007
A further expedition dives the Dva Kapitana (Two Captains) sump to reach a record depth of over 2km (1.2mi).

The Arabika Massif is one of the largest limestone karsts in the Western Caucasus

© Alamy

© Enrique Baquero

How deep is the world's deepest cave?

Where is the planet's deepest subterranean network and what have cavers found?

In 2007, a team of 41 cavers worked their way into the limestone of the Arabika Massif in the Western Caucasus, Georgia, to descend to new depths of the Voronja Krubera cave system. Two branches of this subterranean warren were discovered to reach 1,775 metres (5,823 feet) and 1,920 metres (6,299 feet), but the deepest point – a sump dubbed 'Two Captains' – exceeded the two-kilometre (1.2-mile) mark to become the deepest natural cave in the world at 2,191 metres (7,188 feet).

Essential kit used for casual spelunking (or potholing) includes a hard hat, headlamp, waterproofs, thermals, climbing gear and basic rations for longer expeditions. But the 2007 Krubera caving trip was comprised of professional spelunkers, known as speleologists, who weren't just experienced at exploring caves but specialists in cave sciences including biology, hydrology and geology. The 41 team members spent a total of 29 days mapping out the cave network, as well as recording the temperature and sampling sediments, micro-organisms and speleothems (which include cave formations such as stalagmites). So as well as standard camping gear, sample containers and more unusual scientific devices such as ground-penetrating radar were used to help plan the best possible route ahead.

Georgia (specifically the disputed region of Abkhazia) is home to the top three deepest caves on Earth and, incredibly, Two Captains is known to go deeperstill. Ropes and carabiners in the hands of expert climbers are essential for exploring these incredible depths, as the Voronja-Krubera system includes drops like the Big Cascade, which alone plummets 152 metres (499 feet). ✺

How do jet streams work?

They're a vital component in regulating global weather, but what do jet streams actually do?

Jet streams are currents of fast-moving air that can be found high in the atmosphere of some planets. Here on Earth, when we refer to 'the jet stream', we're typically talking about either of the polar jet streams. There are also weaker, subtropical jet streams located higher up in the atmosphere, but their altitude means they have less of an effect on commercial air traffic and the weather systems in more populated areas.

The northern jet stream travels at about 161-322 kilometres (100-200 miles) per hour from west to east, ten kilometres (six miles) above the surface in a region of the atmosphere that is known as the tropopause (the border between the troposphere and the stratosphere). It's created by a combination of our planet's rotation, atmospheric heating from the Sun and the Earth's own heat from its core creating temperature differences and, therefore, pressure gradients along which air rushes.

In the northern hemisphere, the position of the jet stream can affect the weather by bringing in or pushing away the cold air from the poles. Generally, if it moves south, the weather can turn rather wet and windy; too far south and it will become much colder than usual. The reverse is true if the jet stream moves north, inducing drier and hotter weather than average as warm air moves in from the south.

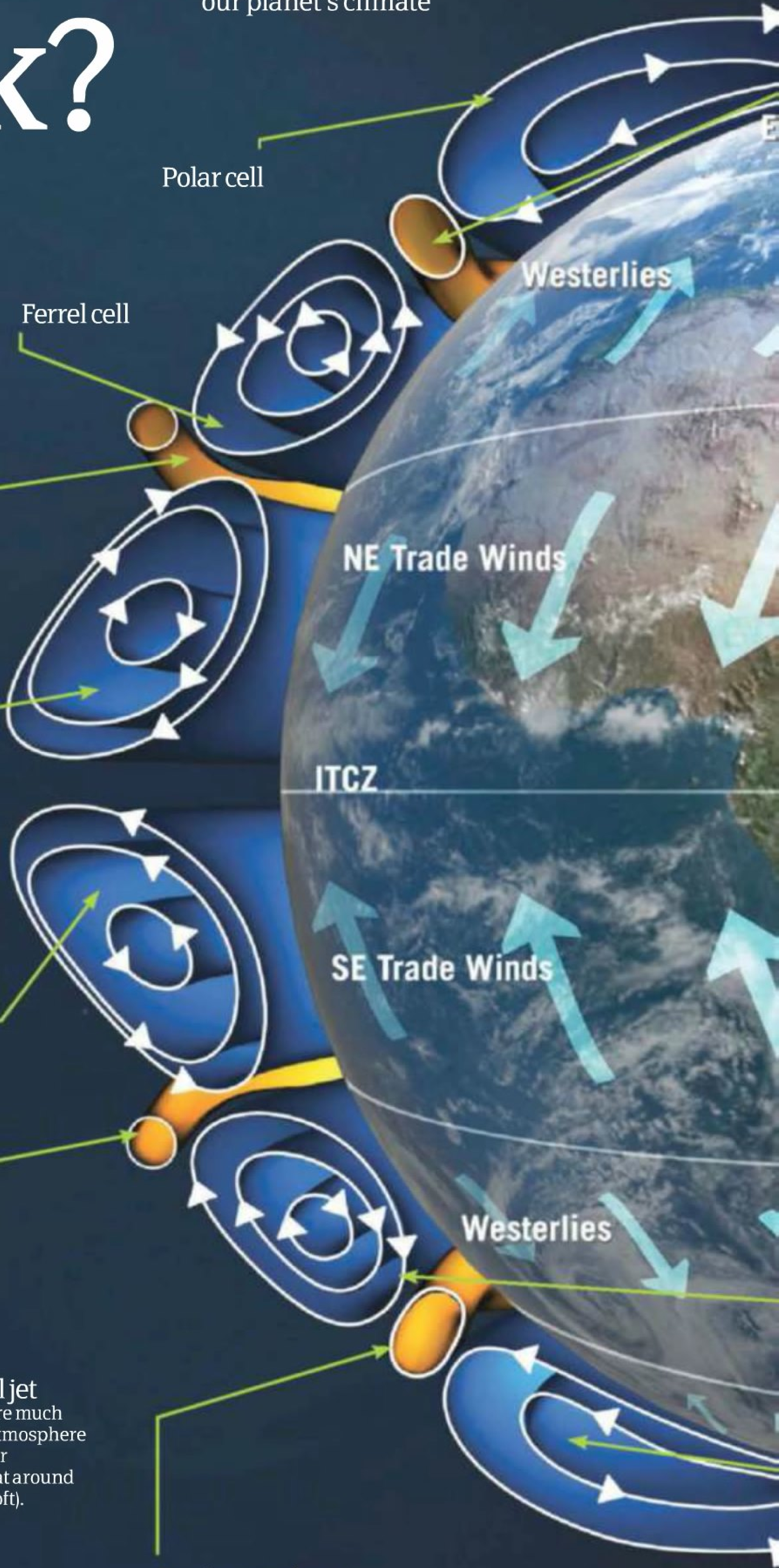
In the southern hemisphere, meanwhile, the jet stream tends to be weakened by a smaller temperature contrast created by the greater expanse of flat, even ocean surface. However, on occasion it can also impact the weather in exactly the same way as the northern jet stream does. ✸

Winds of change

Currents in the jet stream travel at various speeds, but the wind is at its greatest velocity at the centre, where jet streaks can reach speeds as fast as 322 kilometres (200 miles) per hour. Pilots are trained to work with these persistent winds when flying at jet stream altitude, but wind shear is a dangerous phenomenon that they must be ever vigilant of. This is a sudden, violent change in wind direction and speed that can happen in and around the jet stream, affecting even winds at ground level. A sudden gust like this can cause a plane that's taking off/landing to crash, which is why wind shear warning systems are equipped as standard on all commercial airliners.

Earth's jet streams

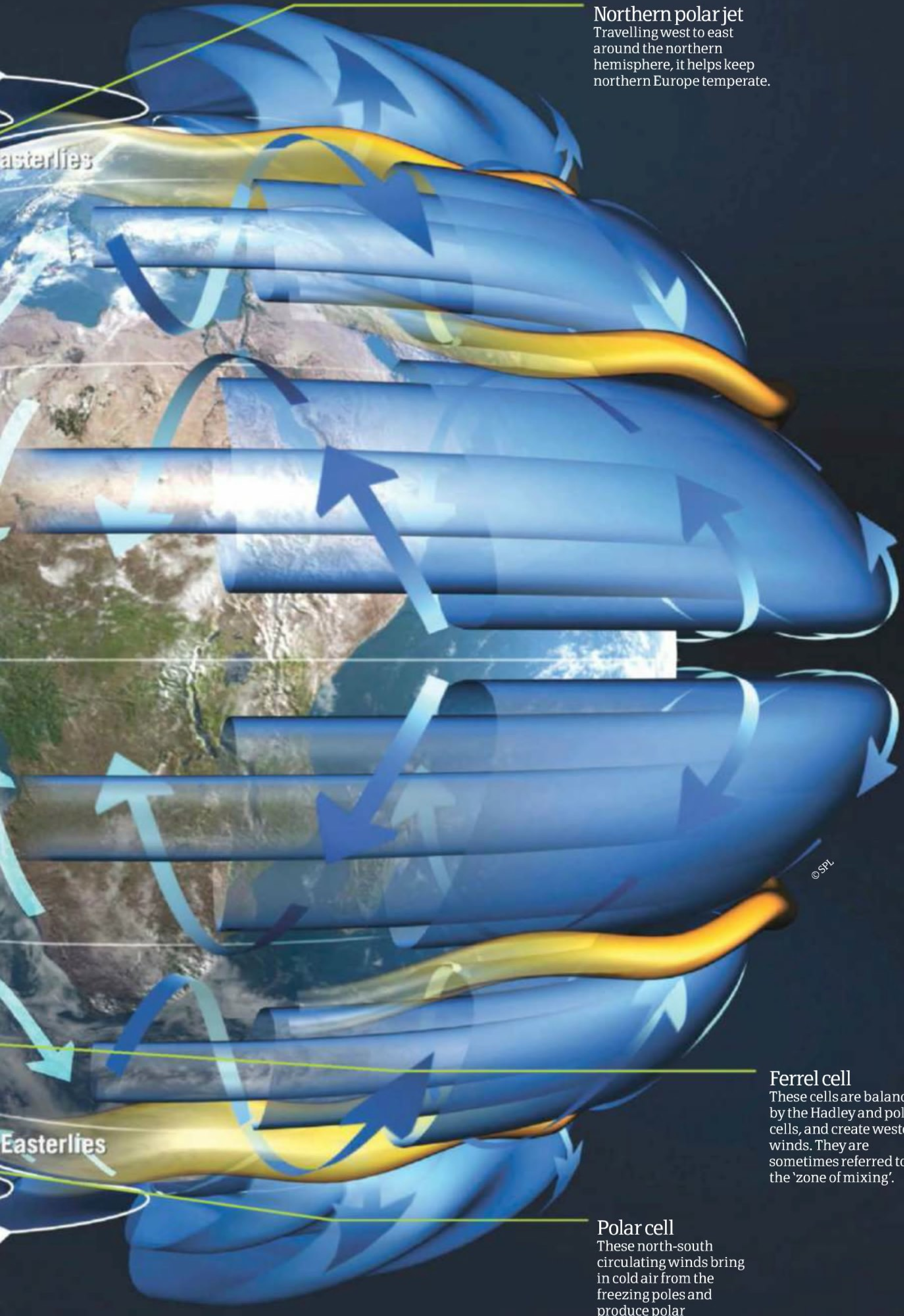
A closer look at some of the invisible phenomena that play a major role in our planet's climate



Hadley cell
This atmospheric cell is partly responsible for the deserts and rainstorms in the tropics.

Subtropical jet
These winds are much higher in the atmosphere than their polar counterparts, at around 17,000m (55,000ft).

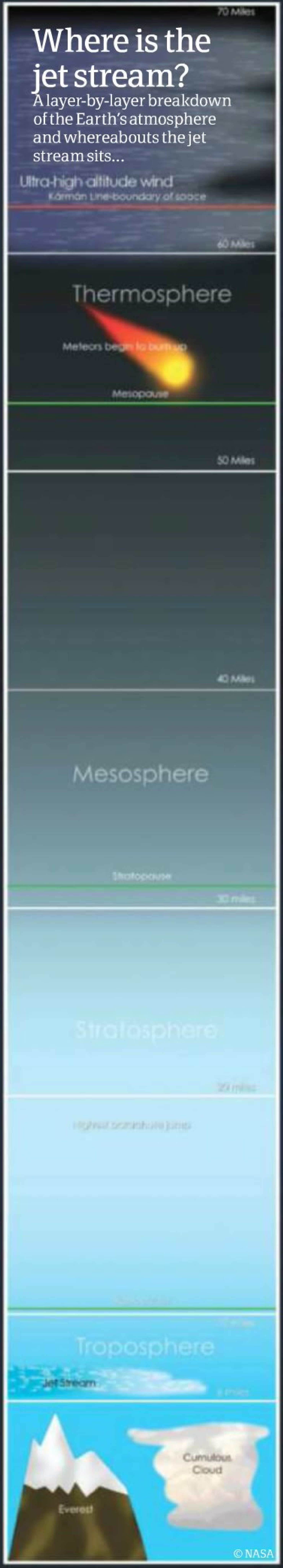
Southern polar jet
The southern hemisphere's jet stream runs around the circumference of the Antarctic landmass.


asterlies
Easterlies
©SPL

Northern polar jet
Travelling west to east around the northern hemisphere, it helps keep northern Europe temperate.

Ferrel cell
These cells are balanced by the Hadley and polar cells, and create westerly winds. They are sometimes referred to as the 'zone of mixing'.

Polar cell
These north-south circulating winds bring in cold air from the freezing poles and produce polar easterlies.



Where is the jet stream?

A layer-by-layer breakdown of the Earth's atmosphere and whereabouts the jet stream sits...

70 Miles
Ultra-high altitude wind
Kármán Line-boundary of space
60 Miles
Thermosphere
Meteors begin to burn up
Mesopause
50 Miles
40 Miles
Mesosphere
Stratopause
30 miles
Stratosphere
20 miles
Highest parachute jump
Troposphere
Jet Stream
Cumulous Cloud
Everest

© NASA

How are double rainbows formed?

What causes this colourful meteorological phenomenon, and are they actually more common than we imagine?

Regular rainbows occur when moisture in the air – commonly rain, but also mist or spray such as that from a waterfall – refracts sunlight in such a way that it is broken up into its constituent colours.

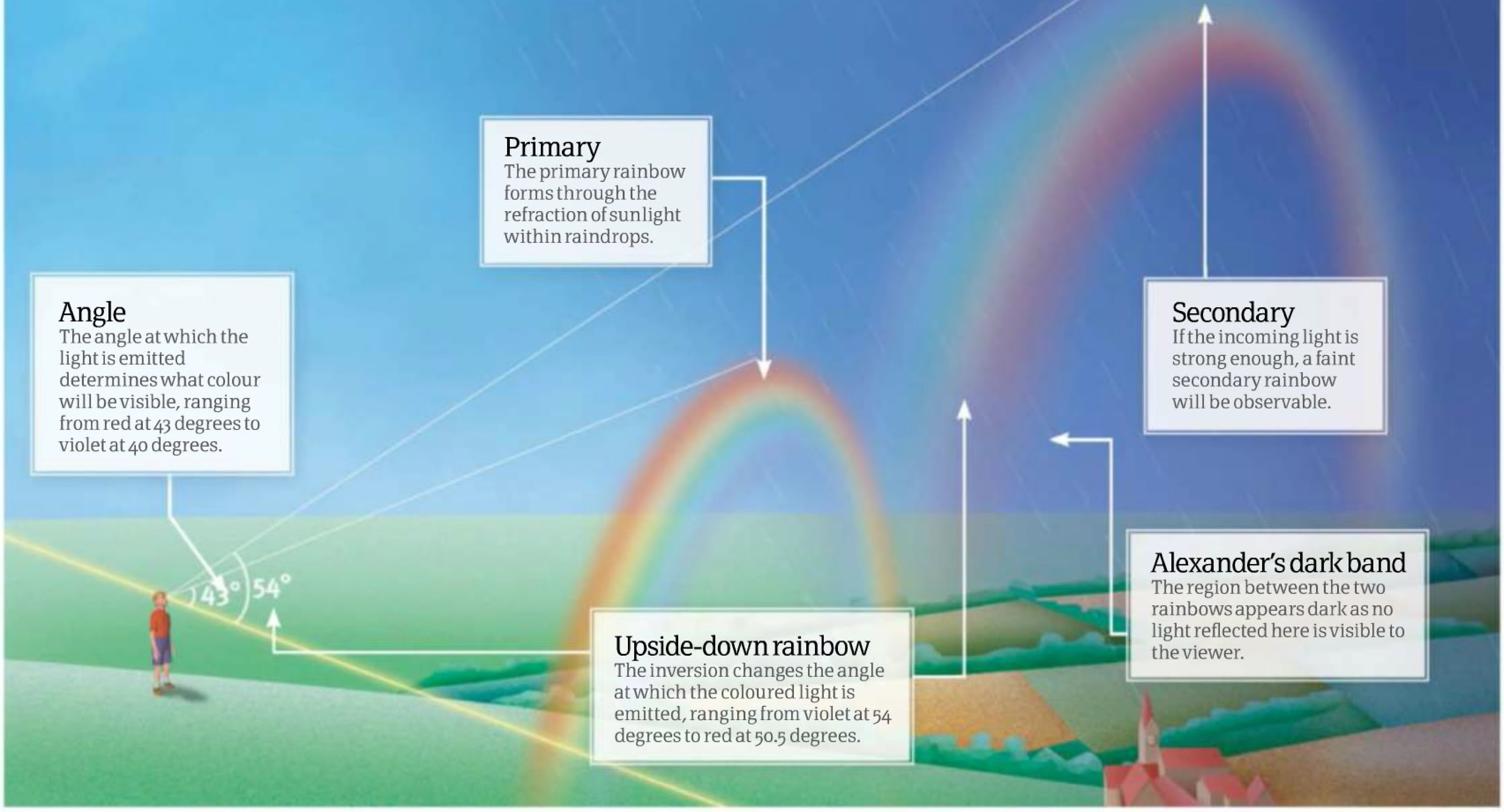
The phenomenon occurs when the Sun is positioned behind you and sunlight passes through the airborne water. The light refracts (bends) inside the droplets and the white light is broken up. Each colour has a different wavelength so, depending on the angle of refraction, a different colour of light will be reflected outwards; the result of this process is what we observe when we see a rainbow.

Every rainbow is accompanied by another, secondary rainbow, but it's usually too dim to see. This double rainbow effect is due to the continued reflection of light inside each water drop. Sunlight is actually reflected twice inside a drop: once to produce the primary rainbow and a second time at the back of the drop. This second reflection inverts the light but undergoes the same refraction, so exits in the same way as before – though upside down.

> “Every rainbow is accompanied by another secondary one, but it's usually too dim to see”

This second reflection reduces the intensity of the sunlight, but it also produces a second inverted rainbow, creating a double arc of multicoloured light in the sky. Interestingly, sunlight can reflect many more times inside a water drop so many more rainbows (three, four or even more) can be produced, but the incoming light is rarely strong enough for these to be visible by the naked eye.

Double rainbow formation



Primary
The primary rainbow forms through the refraction of sunlight within raindrops.

Angle
The angle at which the light is emitted determines what colour will be visible, ranging from red at 43 degrees to violet at 40 degrees.

Secondary
If the incoming light is strong enough, a faint secondary rainbow will be observable.

Alexander's dark band
The region between the two rainbows appears dark as no light reflected here is visible to the viewer.

Upside-down rainbow
The inversion changes the angle at which the coloured light is emitted, ranging from violet at 54 degrees to red at 50.5 degrees.

Why are clouds different shapes?

We explore the elemental factors influencing varying cloud types, and discover what clouds are responsible for specific weather conditions

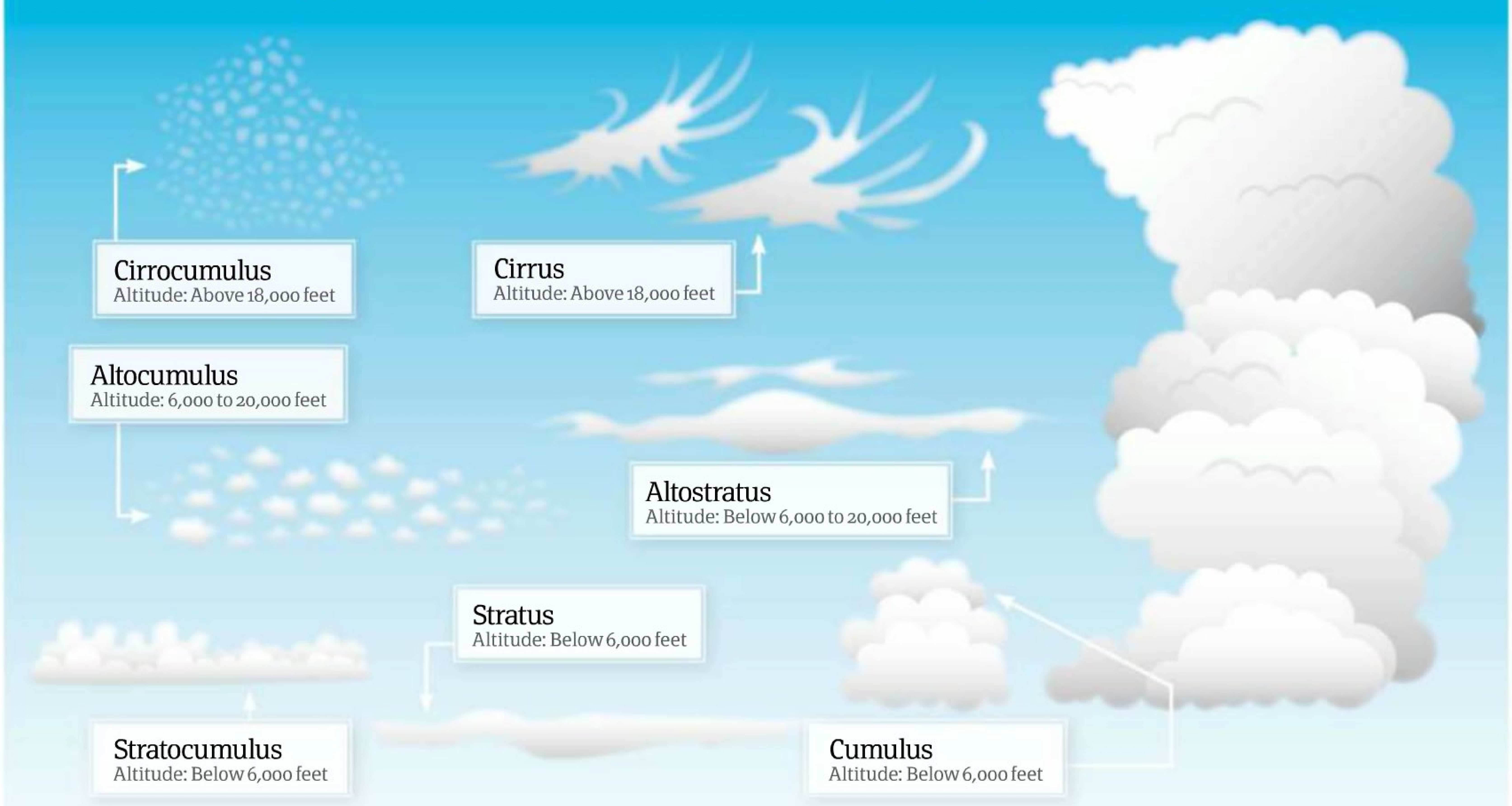
Look up into the sky and you'll notice that clouds shift in shape and size. This is due to there being numerous common types of cloud formation, with each performing a natural role, which is determined by external factors such as altitude, condensation and disposition. These include stratus, cumulus, stratocumulus, altocumulus, cirrus, cirrocumulus and cumulonimbus.

Most cloud formations are produced in environments that are saturated, or where relative humidity is at 100 per cent. Varying mechanisms can activate this process. For example orographic uplift, which occurs as air is forced up due to the physical presence of elevated landmass. As air rises it cools as a result of adiabatic expansion, at a rate of approximately ten degrees Celsius per every 1,000 metres, until saturation occurs. Stratus clouds, for example, form when minimal upward vertical air currents lift a thin layer of air high, which is enough to initiate the condensation of excess water vapour.

Altocumulus clouds are part of the middle order of formations, appearing greyish with dark patchy areas. Often these clouds precede a cold front, and on a warm humid morning indicate approaching thunderstorm activity. Altocumulus clouds are often produced due to turbulent updrafts of air, uplifted by terrain barriers such as mountains, composed of super-cooled water, below freezing, which has not yet crystallised around a condensation nucleus.

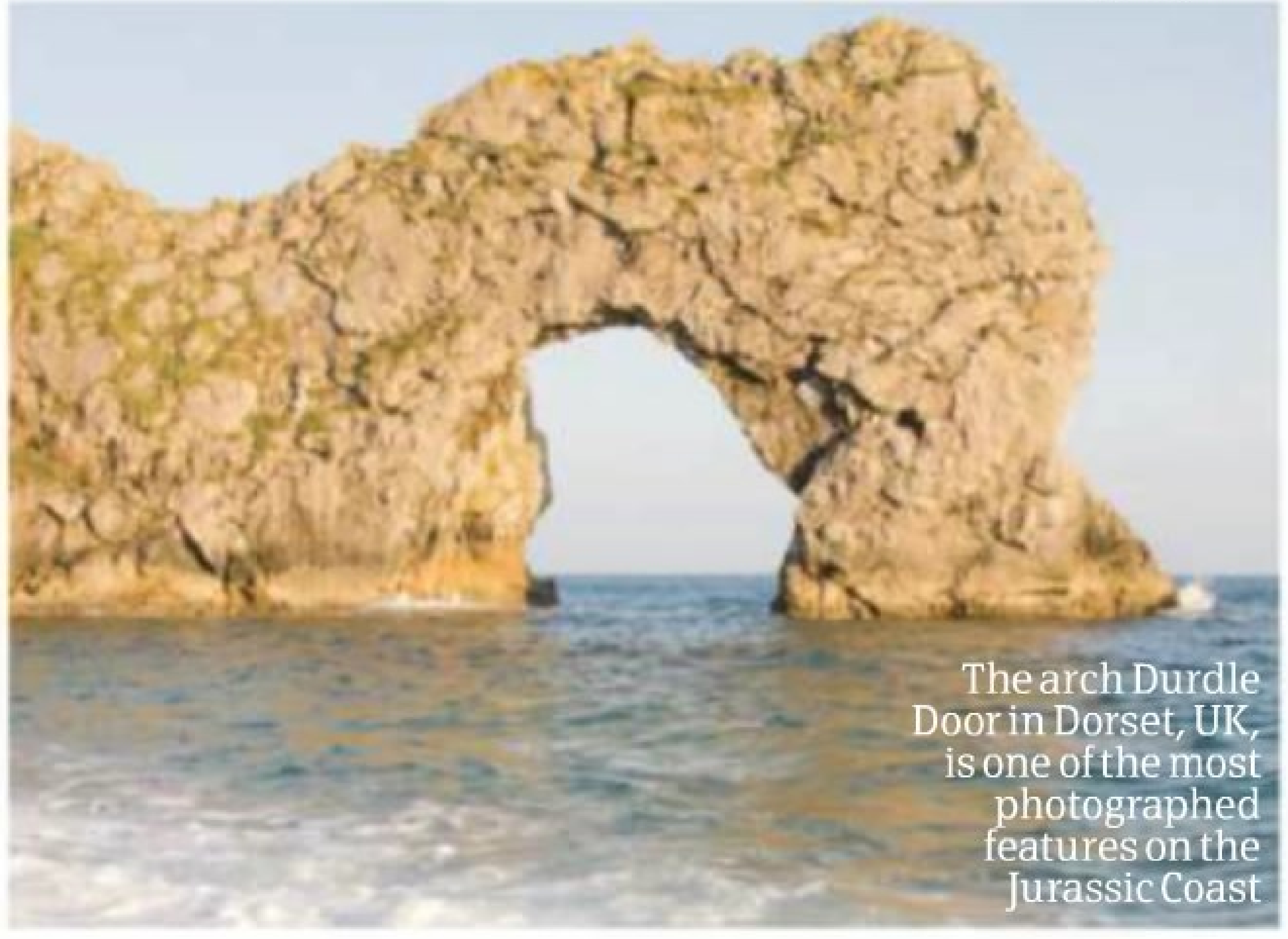
There are several cloud formations at high altitude. Most notable are cumulonimbus, which form if cumulus congestus clouds continue to grow vertically. Ranging from near ground level up to 50,000 feet, this formation releases huge amounts of energy by condensated water vapour. Lightning, hail and violent tornadoes are associated with cumulonimbus clouds. During the formation, condensation carries droplets up and down several times before being released and combining to form raindrops. In larger specimens up-currents become severe, splitting raindrops and ice crystals, before re-combining and falling to the ground. This contributes to a build up of electrical charges and the occurrence of lightning.

Common types of clouds in the troposphere


Cirrocumulus
Altitude: Above 18,000 feet
Cirrus
Altitude: Above 18,000 feet
Altocumulus
Altitude: 6,000 to 20,000 feet
Altostratus
Altitude: Below 6,000 to 20,000 feet
Stratus
Altitude: Below 6,000 feet
Stratocumulus
Altitude: Below 6,000 feet
Cumulus
Altitude: Below 6,000 feet

Why is the coast eroding?

Learn about the amazing processes that are building and breaking our shores right now…



The arch Durdle Door in Dorset, UK, is one of the most photographed features on the Jurassic Coast

Water is not given enough credit for the role it plays in shaping Earth. Tectonic plates and volcanic eruptions are often cited as the culprits for most land features, but it is water and wave action that shapes and constantly reshapes our world's coastlines.

When a wave crashes on the shore it carries sediments that are suspended in the water, and it pushes larger sediments along the ground too. When a wave recedes it also takes sediment with it, but rarely at an equal rate.

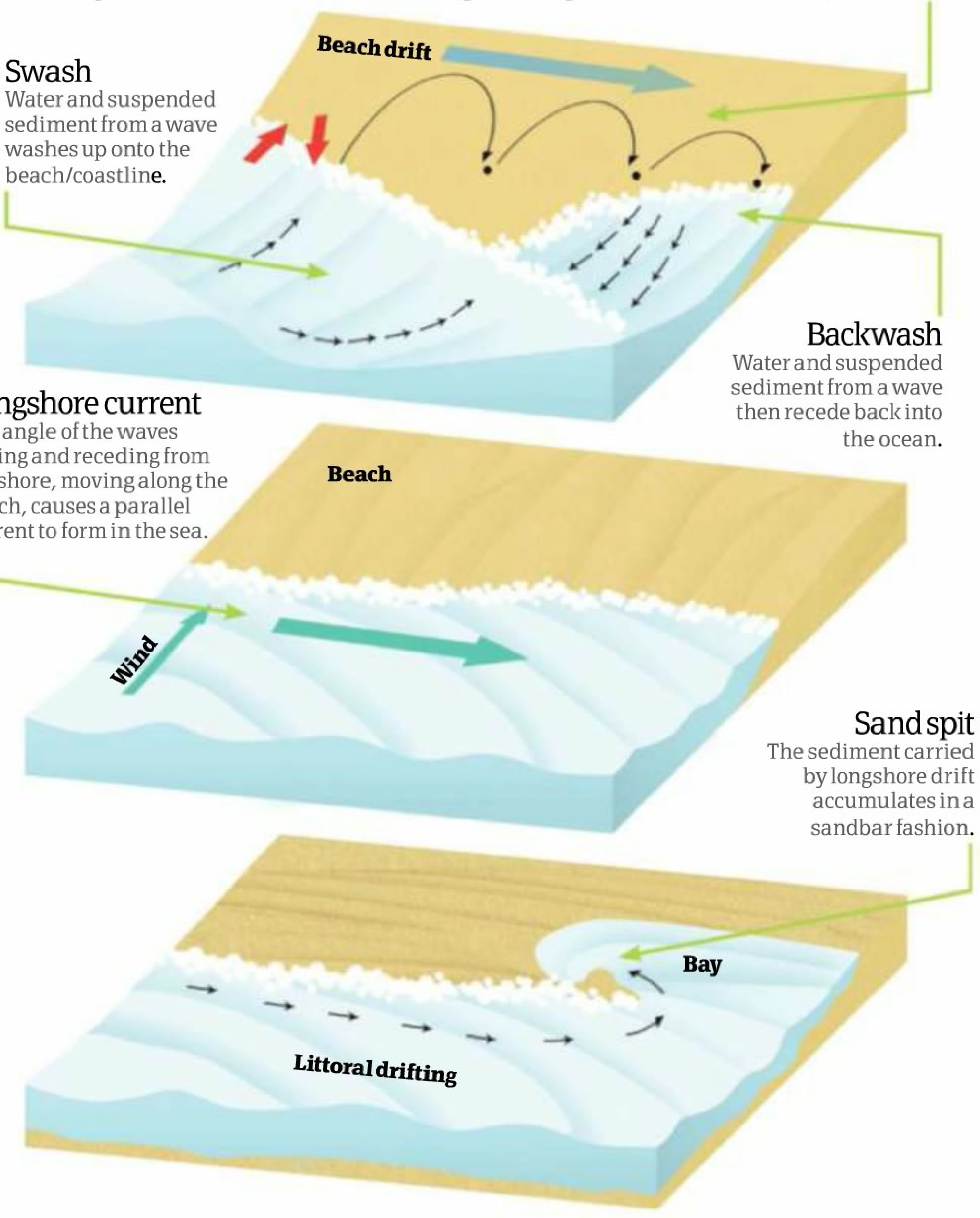
If a wave deposits more sediment than it takes away then this sediment builds up, causing coastlines to extend. Conversely, when more sediment is being removed than added, the coastline recedes or erodes. Coastal erosion is responsible for some of the most amazing landforms we know today, from the Twelve Apostles in Australia to the White Cliffs of Dover in England.

The type of coastline that is created from erosion varies greatly depending on any number of factors, including the strength of the wave action and wind, the sediment composition of the coastline and the types of nearby rock.

Coastal erosion is a very slow process, taking hundreds of years, but scientists believe that climate change is speeding things up. Climate change has caused a rise in sea levels and storm frequency and severity – both of which play a key role in erosion. Indeed, the UK's Environment Agency estimates that the British coastline could erode from 67-175 metres (220-575 feet) over the next 100 years.

Longshore drift currents explained

Longshore drift occurs when waves crash at an angle and flow back at a right angle



Sediment
Sediment is washed ashore and pulled back into the ocean at differing rates. During a longshore drift, the angle of the waves causes the sediment to move along the beach.

Swash
Water and suspended sediment from a wave washes up onto the beach/coastline.

Backwash
Water and suspended sediment from a wave then recede back into the ocean.

Longshore current
The angle of the waves hitting and receding from the shore, moving along the beach, causes a parallel current to form in the sea.

Sand spit
The sediment carried by longshore drift accumulates in a sandbar fashion.

More than one way to wear a rock…

Corrosion

This chemical-based erosion only occurs with certain types of rock, such as chalk or limestone, which are high in calcite. The acidity of the seawater causes a chemical reaction in the mineral, which eats away at it.

Abrasion

This occurs when the sediment suspended in the water (eg sand) is thrown against the shore by the crashing waves. The sediments grind against the land, weakening the structural integrity of the coastline.

Hydraulic action

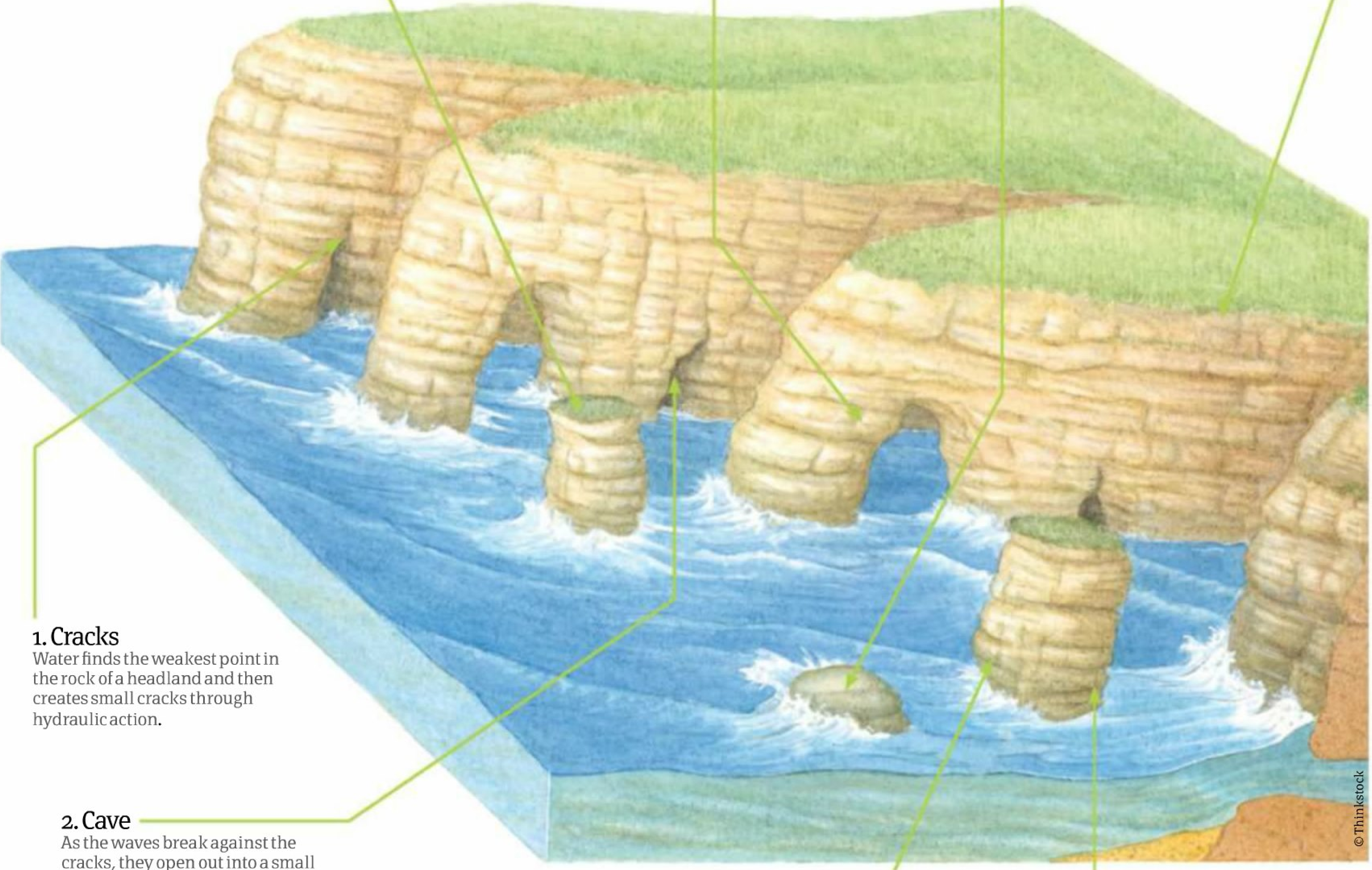
Wave action compresses tiny air pockets within the rock, which eventually causes cracks to form. The cracks get bigger and bigger over many years and eventually develop into caves and so on.

Attrition

Continued wave action hurls stones and other material at the land, which smooths and breaks up the coastal rocks, dislodging them from the land and adding to the sediment. These collide with other rocks on the shore.

Sea stack formation

Discover how these rocky towers develop and what fate awaits them in the long term…



1. Cracks
Water finds the weakest point in the rock of a headland and then creates small cracks through hydraulic action.

2. Cave
As the waves break against the cracks, they open out into a small cave, which becomes larger and larger as time goes by.

3. Arch
Wave action from both sides of the cave causes it to break open, forming an arch-shaped structure over the sea.

4. Stack
Eventually, the meeting point of the tip of the arch and the headland will collapse, leaving a free-standing stack, separated entirely from the headland.

5. Rock type
Medium-density rocks like sedimentary or volcanic rocks usually form sea stacks; softer rocks like clay erode too quickly.

6. Top of stack
Sea stacks are a popular nesting site for seabirds as they are isolated and difficult for predators to reach.

7. Stump
The stack gets eroded away even further until it eventually leaves just a stump, which is often covered at high tide.

8. Headland
Harder-density rocks remain jutting out into the ocean where the coastline has receded behind it, usually creating bays.

© Thinkstock

The different shapes of coastlines

Bay
Bays are inlets of water that form between headlands. They have low-energy wave action and reduced winds due to the surrounding land.

Atoll
Atolls are horseshoe- or ring-shaped coral reefs, with an inner lagoon, formed when a fringing reef develops around a submerging island.

Delta
These occur when rivers flow into a body of water, like the sea. The river's flow is stemmed so its sediment builds up around the river mouth.

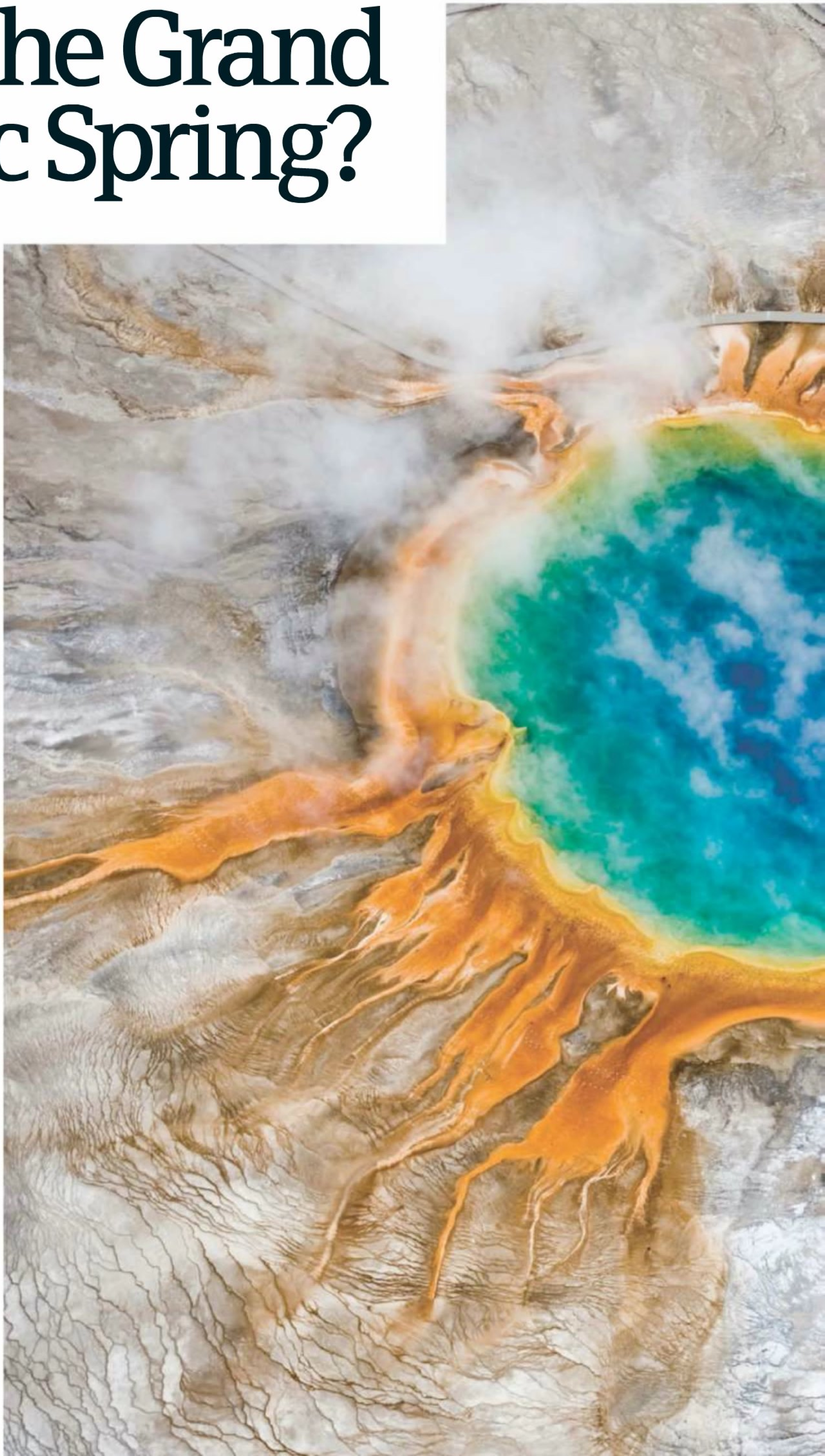
Fjord
A narrow inlet of water with a steep shoreline. They form when glaciers cut a deep valley into bedrock, which floods as the glacier recedes.

Fringing reef
These are coral reefs that develop around an island, creating a fringe. Coral polyps build on top of eachother to form huge living structures.

Blowhole
These occur when a sea cave extends to form a small hole on top of the headland. Wave action forces water up through it, up to several metres.

What is the Grand Prismatic Spring?

What makes it so hot and why is it so colourful?



Yellowstone Park, Wyoming, became the world's first national park when US President Ulysses S Grant signed it into law in 1872. It's not hard to see why the government wanted to preserve this area of great natural beauty, especially with incredible features such as this: the world's third-largest hot spring.

The Grand Prismatic Spring is Yellowstone's largest at a remarkable 90 metres (295 feet) wide and 50 metres (164 feet) deep, and works like many of the park's hydrothermal features. Water deep beneath the ground is heated by magma and rises to the surface unhindered by mineral deposits. As it bubbles to the top it cools and then sinks, only to be replaced by hotter water coming from the depths in a continuous cycle. The hot water also dissolves some of the silica in the rhyolite rocks in the ground, creating a solution that's deposited as a whitish siliceous sinter onto the immediate land surrounding the spring.

So what makes all the beautiful colours on display? You may be surprised to know that it's not related to chemicals. The iridescent pigments are actually caused by bands of microbes – cyanobacteria – that thrive in these warm to hot waters. Moving from the coolest edge of the spring along the temperature gradient, the calothrix cyanobacteria lives in temperatures of no less than 30 degrees Celsius (86 degrees Fahrenheit), can live out of the water too and produces the brown pigment that frames the entire spring. Phormidium, meanwhile, prefers a 45-60-degree-Celsius (113-140-degree-Fahrenheit) range and creates the orange pigment, while synechococcus enjoys temperatures of up to 72 degrees Celsius (162 degrees Fahrenheit) and is responsible for the yellow and green.

The deep blue colour that is visible right in the centre is the natural colour of the water and is too hot for most bacteria, although it's suspected that aquifex, a microbe that thrives in near-boiling water, lives off the hydrogen gas dissolved in the emerging Grand Prismatic Spring's waters.

Can I drink it?

No. While there's no problem with the water itself, the cyanobacteria that give the Grand Prismatic Spring its characteristic colouration can cause all sorts of problems if ingested. They produce a range of dangerous compounds including neuro- and hepatotoxins that cause vomiting, rashes, numbness and worse: long-term liver damage, nervous disorders and even cancer. This isn't exclusive to humans; cyanobacteria are a common sight all over the world and, where they bloom in prolific numbers, they pose a serious threat to local ecosystems. That's one reason why the area immediately surrounding the spring is so barren.

What are the Devil's Marbles?

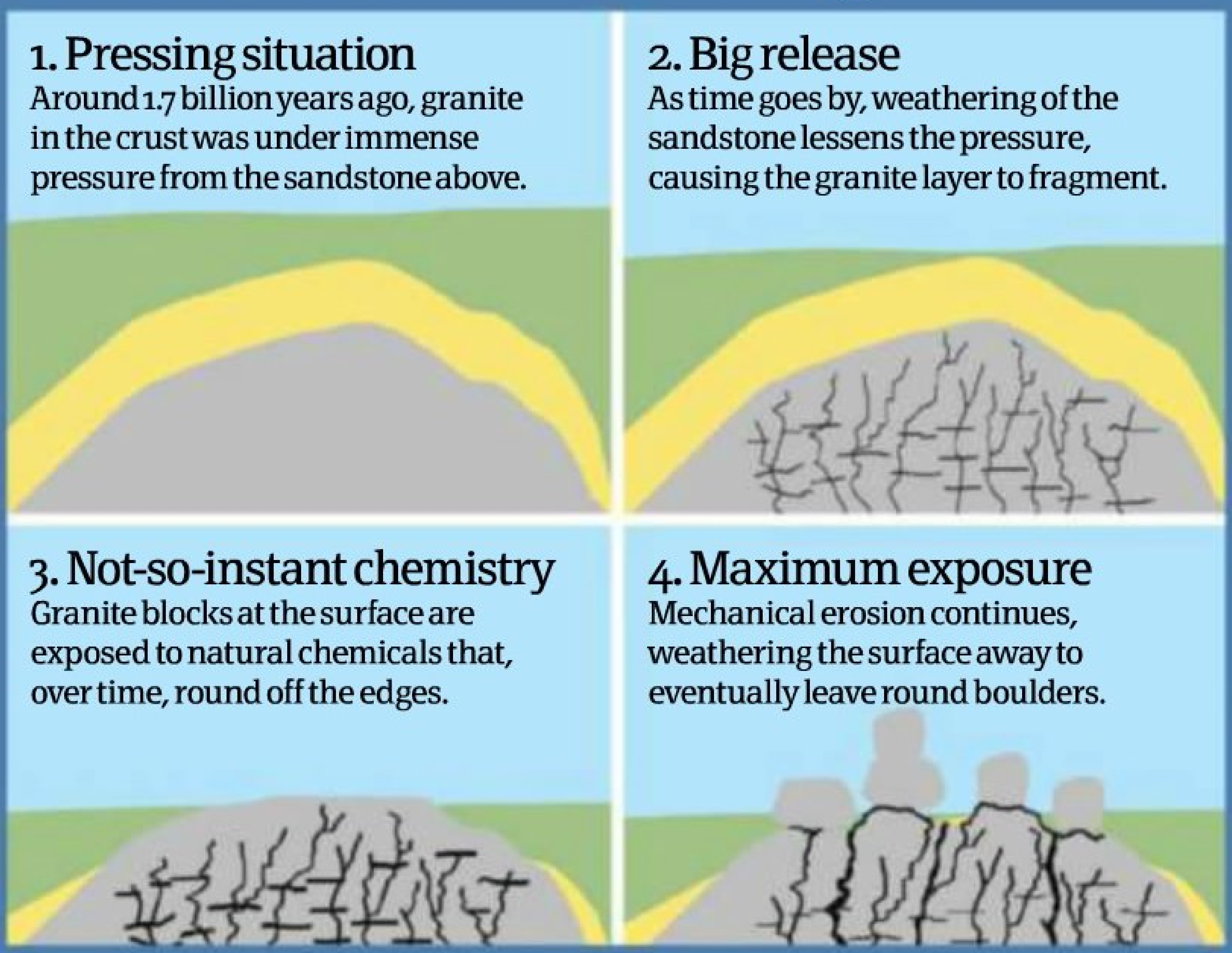
Part of Australia is littered with odd boulders, but where did they come from?

You can understand how this odd natural feature got its name: in the middle of Australia's Northern Territory wilderness, near the town of Wauchope, hundreds of rounded boulders are strewn across the arid landscape. Some are piled in heaps, while others are poised atop rocky outcrops in a seemingly deliberate attempt to balance them. The Aboriginal owners of this 1,800-hectare (4,453-acre) reserve call it Karlu Karlu, which is also derived from a traditional belief that a supernatural being placed the boulders for its own unfathomable amusement. And while the reality might not involve the paranormal, the science is just as interesting.

The Devil's Marbles started life nearly 2 billion years ago as the magma cooled in the Earth's crust to form the igneous rock granite. On top of the granite, a thick sedimentary layer of sandstone formed that compressed the granite under its immense weight. Over millions of years, the sandstone gradually eroded, simultaneously releasing the pressure and causing the granite to expand and then crack into roughly cube-shaped blocks.

Once the sandstone was completely eroded, the angular blocks of granite were subject to erosion themselves. But granite is a significantly harder material than sandstone, so the boulders you can see now are a lot more resistant to the same chemical and mechanical weathering. A combination of water and acidic chemicals naturally present in the atmosphere rounds off the points of the blocks to leave smoother rocks, while the great difference in day and night temperatures expands and contracts the rock forms, peeling off layers to leave the 'marbles' we see today.

Marbles in the making



1. Pressing situation
Around 1.7 billion years ago, granite in the crust was under immense pressure from the sandstone above.

2. Big release
As time goes by, weathering of the sandstone lessens the pressure, causing the granite layer to fragment.

3. Not-so-instant chemistry
Granite blocks at the surface are exposed to natural chemicals that, over time, round off the edges.

4. Maximum exposure
Mechanical erosion continues, weathering the surface away to eventually leave round boulders.

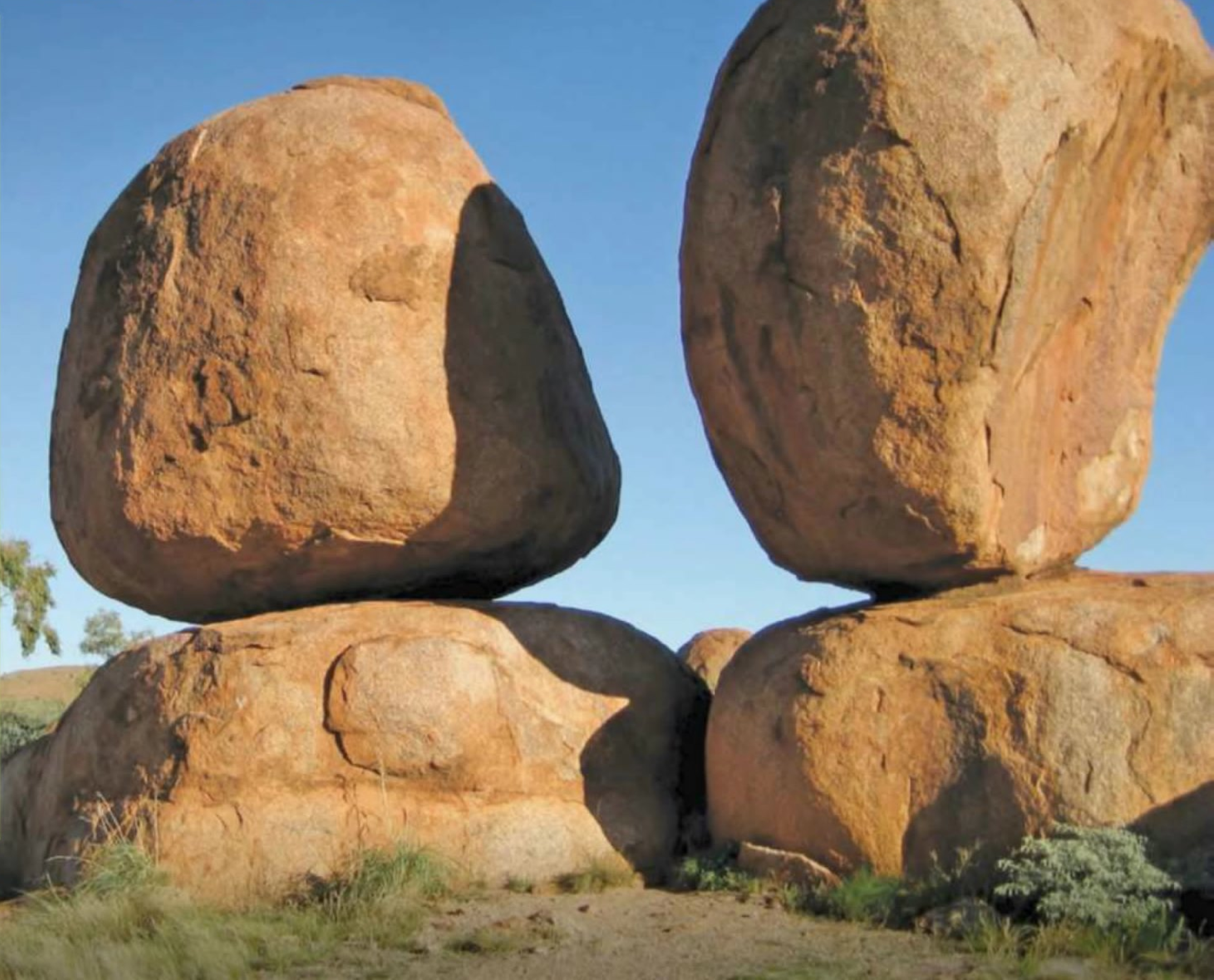
Aussie rocks

Wave Rock
This distinctive Australian rock is found near Perth, Western Australia. It's shaped like a 14-metre (46-foot)-high wave and is 110 metres (361 feet) long.

Uluru
Easily Australia's most well-known rock, Uluru (formerly Ayers Rock) is 348 metres (1,142 feet) high, and is Earth's biggest monolith.

©Jan van der Hoeven

Mount Augustus
Mount Augustus is much bigger than Uluru, at 860 metres (2,820 feet) high, but is a monocline, rather than a monolith.

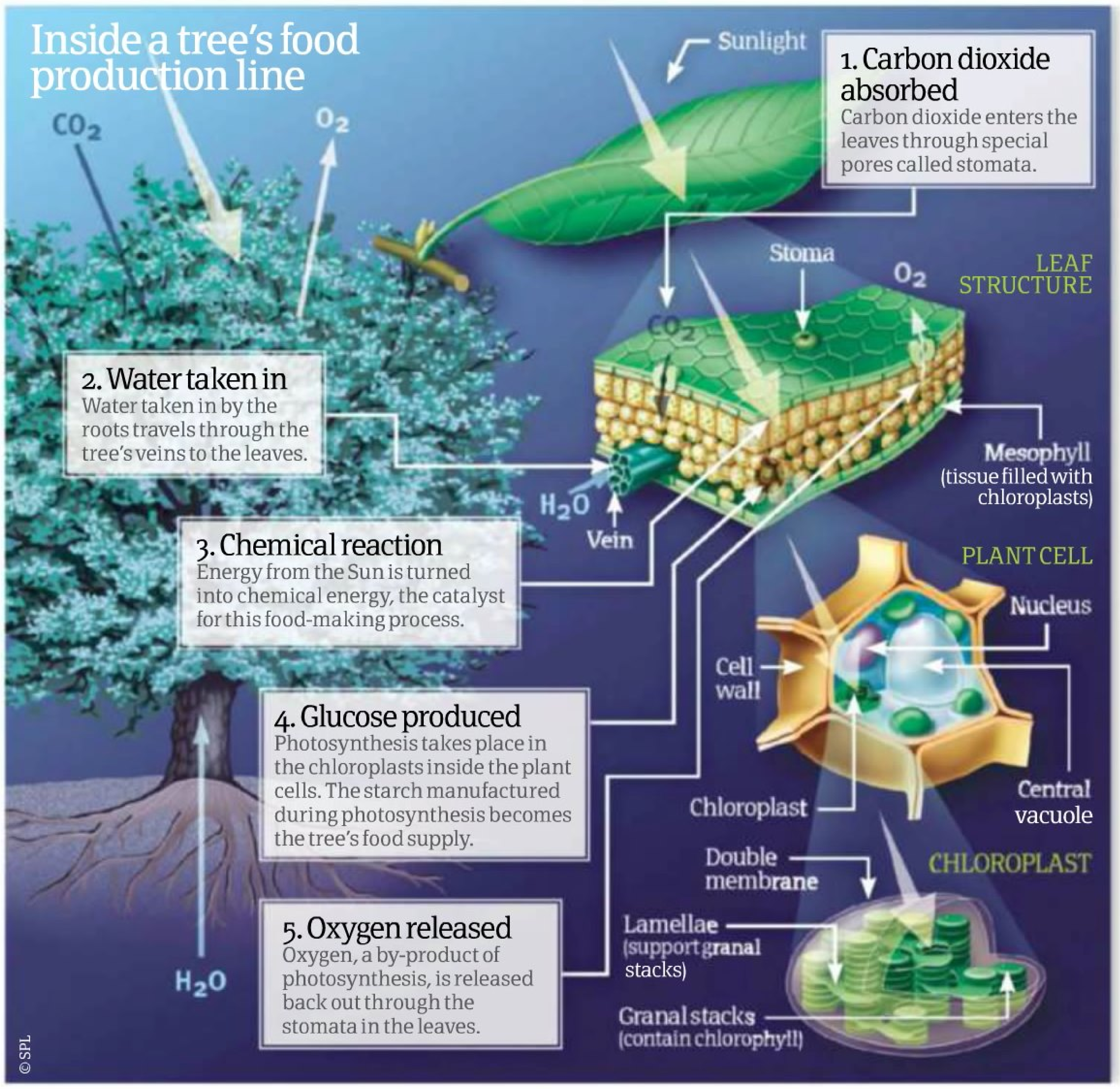


What's inside a tree?

How do these large plants grow, nourish themselves and provide oxygen for us?

Trees are oversized plants that become so big that they require a woody stem to support their weight. They are amazing natural air filters, capable of absorbing harmful carbon dioxide and turning it into oxygen. They also clean the soil, provide habitats for wildlife, muffle noise pollution and prevent soil erosion.

Like all plants, trees harness energy from the Sun to convert carbon dioxide and water into glucose and oxygen. Sunlight is the catalyst for photosynthesis, which takes place within the plant's cells, inside structures called chloroplasts. If you look at a leaf under a microscope you can see the tiny chloroplasts, which are green due to chlorophyll – this green pigment is vital as it traps the energy which powers photosynthesis.



Inside a tree's food production line

1. Carbon dioxide absorbed
Carbon dioxide enters the leaves through special pores called stomata.

2. Water taken in
Water taken in by the roots travels through the tree's veins to the leaves.

3. Chemical reaction
Energy from the Sun is turned into chemical energy, the catalyst for this food-making process.

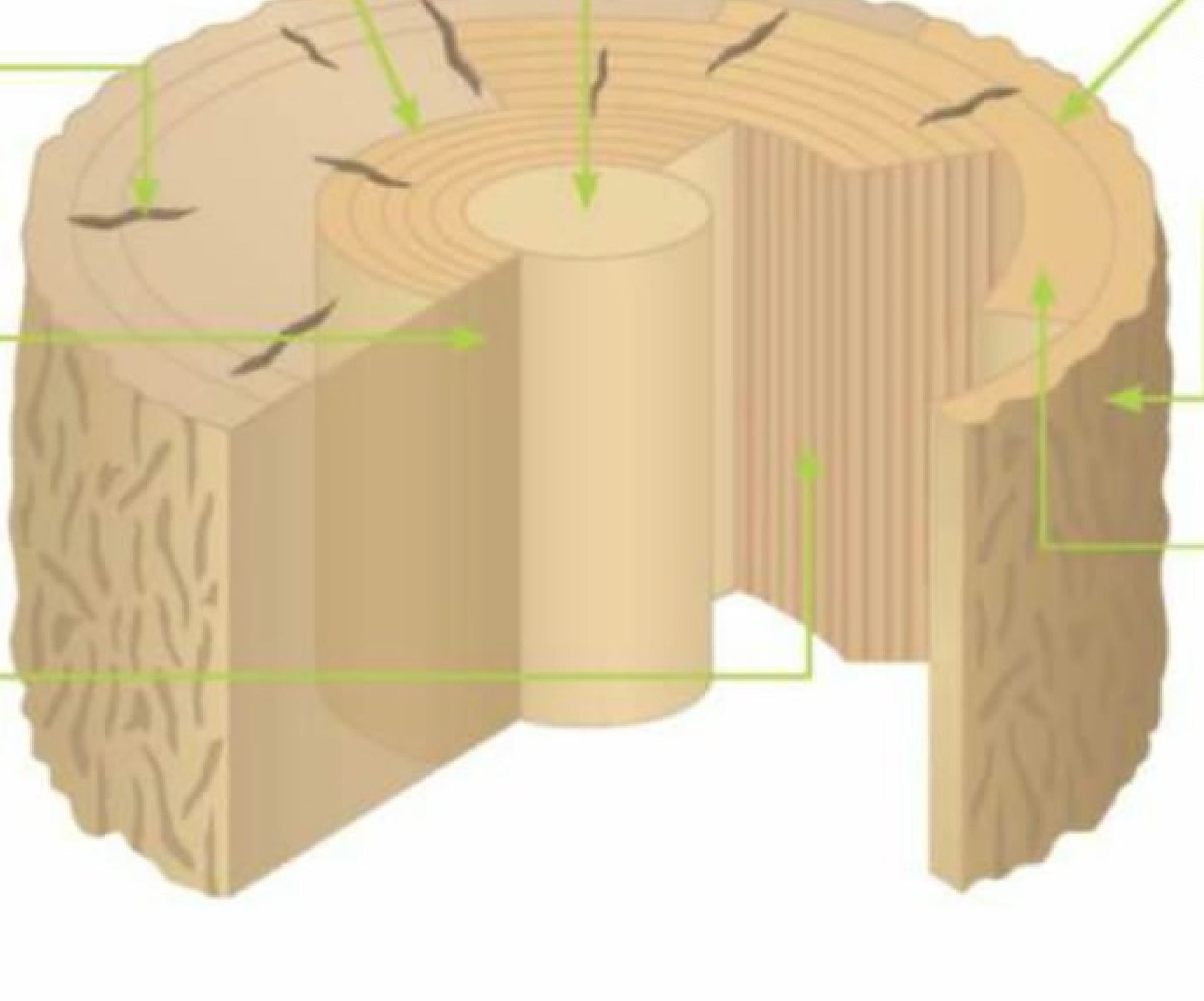
4. Glucose produced
Photosynthesis takes place in the chloroplasts inside the plant cells. The starch manufactured during photosynthesis becomes the tree's food supply.

5. Oxygen released
Oxygen, a by-product of photosynthesis, is released back out through the stomata in the leaves.

© SPL

Trunk structure

One of the main differences between flowering plants and trees is the woody stem. You can tell a lot from looking at the cross-section of a tree trunk, including its age and past environmental conditions.



Growth rings
Thick rings indicate excellent growth conditions (eg plenty of water), while thin rings suggest a lack of nutrition. By counting the rings you can calculate the number of seasons (or years) a tree has lived.

Wood ray
This passageway enables nutrients and water to be distributed horizontally through the trunk from pith to phloem.

Heartwood
This darker layer, which surrounds the core of the trunk (the pith), consists of dead sapwood to support the weight of the trunk and branches.

Sapwood
Often paler than the rest of the trunk, the sapwood is the living wood inside a trunk. This layer containing structural xylem is capable of transporting raw sap to the leaves.

Pith
The pith is the relatively soft, nutrient-rich tissue that makes up the core of the trunk and helps promote sapling growth.

Phloem
Just below the bark is the phloem, a tissue that transports sap and glucose produced by photosynthesis up and down the tree.

Bark
This fibrous outer layer consists of hardened dead cells that protect the trunk from harmful external forces.

Cambium layer
This tissue layer contains active cells that constantly divide, enabling outward growth that increases the trunk's diameter. The new cells produced form the ring markings, which tell us more about the tree from season to season.

How do trees manage to stay hydrated?

In order to obtain water for photosynthesis, the tree's root hairs absorb moisture from the soil, entering tubular xylem cells through a process called osmosis. Because water is constantly evaporating from the leaves at the top of the tree (a process called transpiration), negative pressure is created in the xylem, which draws water up into the cells from below. The xylem tissues in the trunk are rigid. A tree's internal transport system enables water, food and other nutrients to be delivered to all parts of the tree, much like arteries and capillaries in the human body.

Rock pythons have a diverse diet which includes everything from small antelopes to crocodiles

© SPL

© G J Alexander

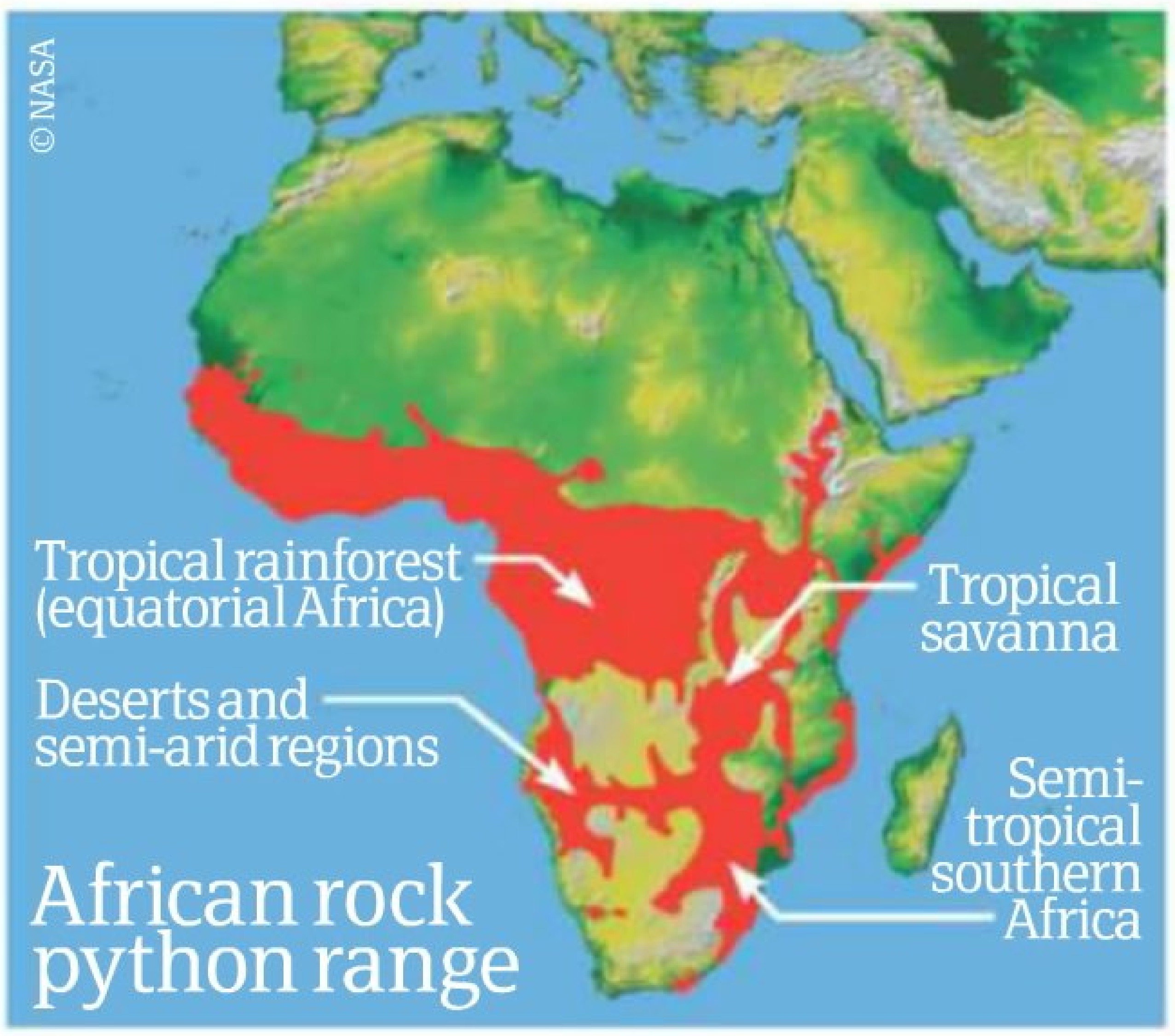
How do rock pythons consume their prey?

Discover how Africa's largest snake kills and consumes its prey

Despite being non-venomous, the python remains one of the world's most dangerous serpents. The African rock python, in particular, is a very deadly assassin, and is also notorious for being ill-tempered.

Pythons incapacitate their prey by literally squeezing the life out of them, coiling their long – sometimes seven-metre (23-foot) – bodies around the victim and tightening their grip until the animal, unable to breathe, eventually suffocates. That done, the python then sets about consuming their meal… in one go.

Equipped with a set of highly flexible jaws, stretchy skin and ribs hinged with extra-supple tissue, the African rock python can down its quarry whole. First the python slides its mouth over the head of the prey and then gradually moves its body along the length of the animal with the help of an expandable throat and abdomen. The animal is then digested over a matter of hours, or even days if it's particularly large. Following such a meal, the python need not eat again for several weeks.


Tropical rainforest (equatorial Africa)
Deserts and semi-arid regions
Tropical savanna
Semi-tropical southern Africa
African rock python range

© NASA

The statistics…

© Tigerpython

Rock pythons

Type: Reptile

Genus: Python sebae

Diet: Carnivore

Life span in wild: Up to 25 yrs

Weight: Up to 100kg (220lb)

Size: Up to 7m (23ft)

How do birds breathe?

Due to an exceedingly high metabolic rate and oxygen demand, birds sport an efficient, refined respiratory system

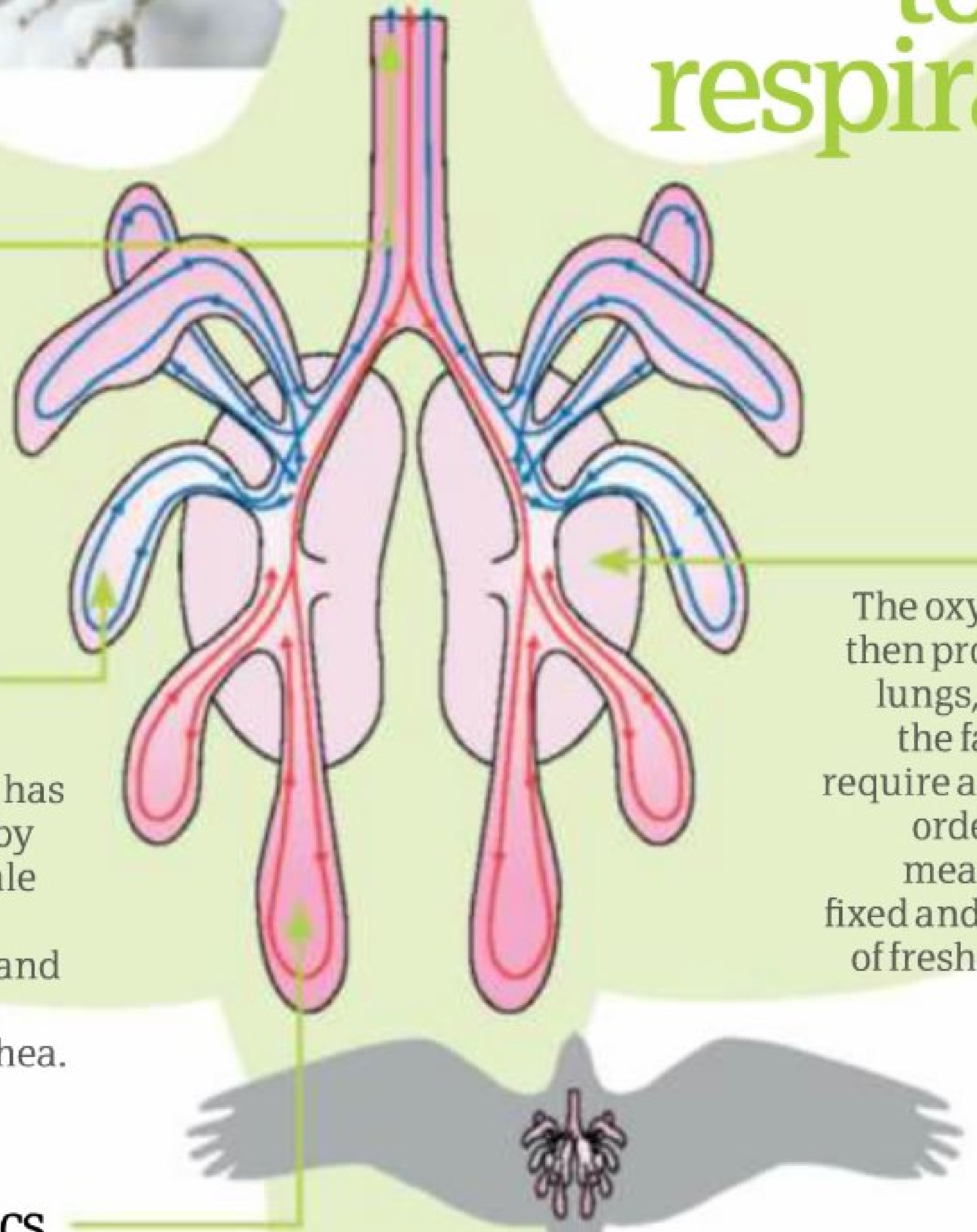
Birds breathe by partnering a pair of lungs, which do not have a diaphragm, with a system of internal air sacs that act as bellows. The reason for this is due to birds' high metabolic rate and oxygen demand when flying; a constant stream of oxygen-rich air is needed in order to process and remain active.

This would not be possible with the bi-directional lungs of mammals because, with mammals, oxygen-rich air is mixed with oxygen-deficient, stale air during the breathing process. This increased stale air reduces the amount of oxygen that can be processed inside the lungs at any one time.

However, with birds' lungs a unidirectional flow is made possible by separating the pump part of the breathing process (the air sacs) with the absorption part (the lungs), so that a constant oxygen-rich stream of air can be maintained. Avian lungs do not process oxygen with alveoli as mammal lungs do, but instead absorb it through honeycombed-structured passages that are referred to as parabronchi. The oxygen then passes into air vesicles, which themselves contain oxygen/carbon dioxide trading capillaries.

© Mdf

A guide to bird respiration



1. Throat
Air passes into the bird normally through the trachea during flight.

2. Rear air sacs
The gathered oxygen-rich air then enters the bird's rear air sacs, which in turn act as bellows, filtering the air into the lungs.

3. Lungs
The oxygen-rich air is then processed by the lungs, which, due to the fact they do not require a diaphragm in order to pump air, means they have a fixed and constant flow of fresh air to process.

4. Forward air sacs
Once the oxygen has been processed by the lungs, the stale air enters the forward air sacs and is then exhaled through the trachea.

* * *

While wasps have earned something of an unpopular reputation, they are actually invaluable for keeping pests in check

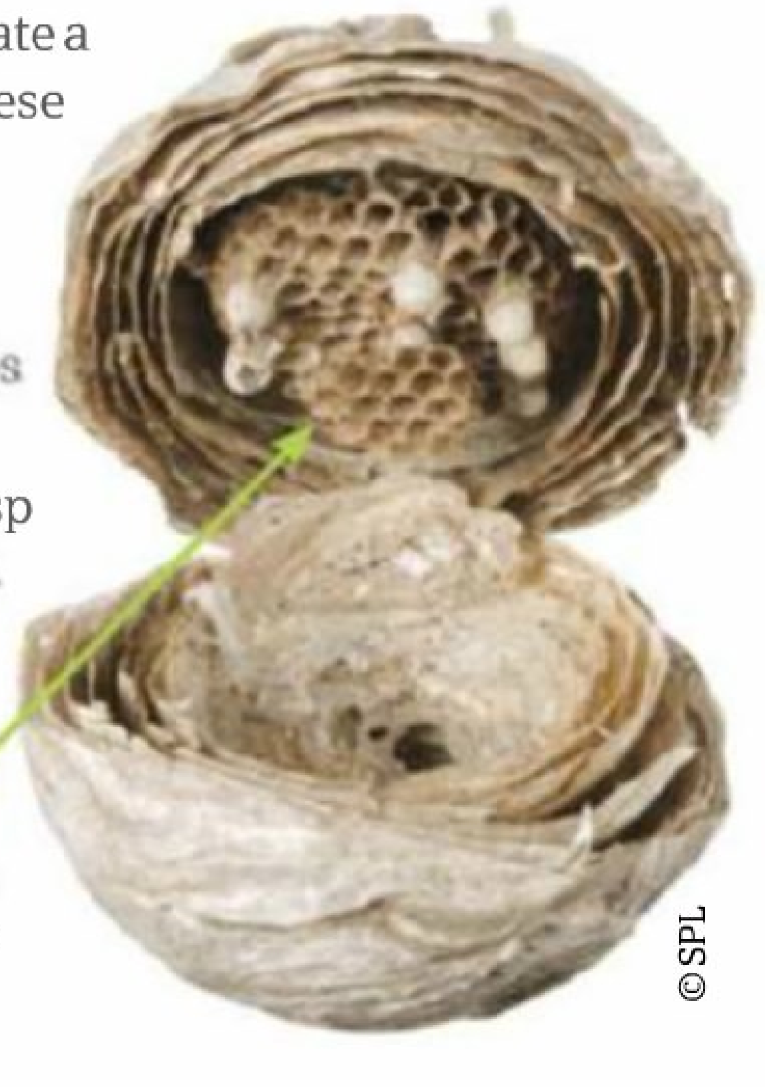
What's inside a wasp nest?

Find out how this predatory insect constructs its papery home

When a queen wasp comes out of hibernation she begins looking for a site to build a nest. She starts by creating a petiole, which forms the main stalk from which the rest of the nest will hang (like the petiole stalk attaching a leaf to its stem). Wasps collect weathered wood and plant matter with their strong mandibles and chew it up. The papery matter is then mixed with saliva to make a paste for nest construction – even in awkward crevices and cavities, such as a roof's eaves.

The queen's next job is to build a small framework of downward-facing hexagonal cells that form the main body, which is used for brood rearing. After building the first cell at the end of the petiole she adds another six around that, and so on until the nest has grown to about the size of a walnut.

Inside each cell, the queen lays an egg to create a starter brood of worker females. Eventually, these hatch into larvae and the queen will stop nest building to spend about a month looking after these young wasps. Once they are mature enough to fend for themselves, the young wasps then take on the role of workers and resume construction. The world's biggest recorded wasp nest reached a length of 3.7 metres (over 12 feet). With the workers now active, the queen can focus on egg-laying and rearing larvae.


© SPL

Core
The heart of the wasp nest is where not only the structure itself begins, but the colony too, as the queen lays the first of many broods of eggs.

How do killer whales hunt?

To merely call them the wolves of the sea is a gross underestimation

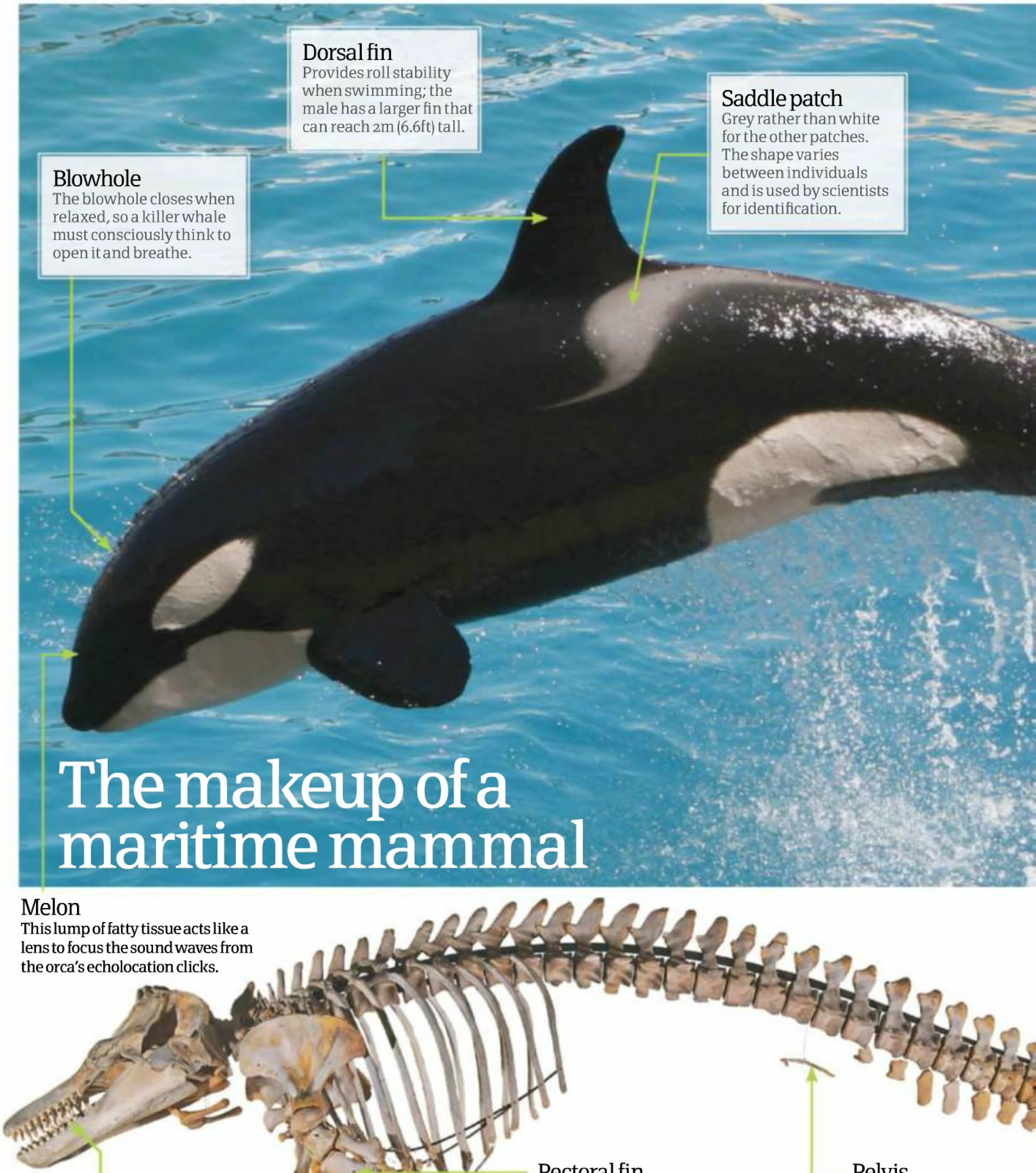
Killer whales aren't whales (they are more closely related to dolphins) and it's not fair to call them killers either. There are no confirmed cases of fatal attacks on humans by killer whales in the wild. But they are incredibly intelligent hunters – probably second only to humans. Killer whales, or orcas, can swim at 56 kilometres (35 miles) per hour (or 30 knots), they have teeth eight centimetres (three inches) long and their echolocation system allows them to find prey in complete darkness. But what really sets them apart is their ability to plan, improvise and work as a team.

Orcas live in loose family groups called pods, of five to seven individuals. In the wild their life span can be 60 years or more but the infant mortality rate is very high; up to half will die before they are seven months old. This is mainly due to the difficulty of finding enough food. Killer whales are mammals and their warm-blood metabolism uses a lot of energy. An adult needs 230 kilograms (510 pounds) of food a day.

To feed this appetite, some subspecies prey on schools of fish by circling below them and releasing a stream of bubbles to confuse them. Others have learned that they can catch sharks by flipping them on to their backs to induce a sort of panic stun, known as tonic immobility. The killer whales that hunt among the Arctic sea ice catch seals and walruses by knocking them off ice floes into the water (see 'Hunting as a pack' boxout).

These are not purely instinctive behaviours; orcas will teach their young, often deliberately catching and releasing a seal several times to allow them to practise hunting. In 2005 scientists observed a killer whale regurgitating fish at the water's surface to lure seagulls down before catching the birds. Four other orcas subsequently learned this tactic.

The makeup of a maritime mammal



Dorsal fin
Provides roll stability when swimming; the male has a larger fin that can reach 2m (6.6ft) tall.

Saddle patch
Grey rather than white for the other patches. The shape varies between individuals and is used by scientists for identification.

Blowhole
The blowhole closes when relaxed, so a killer whale must consciously think to open it and breathe.

Melon
This lump of fatty tissue acts like a lens to focus the sound waves from the orca's echolocation clicks.

Teeth
The front ones are angled slightly forwards, so they aren't wrenched loose by struggling prey.

Pectoral fin
Unlike the dorsal and tail fins, the pectoral fin has bones, including a five-fingered 'hand'.

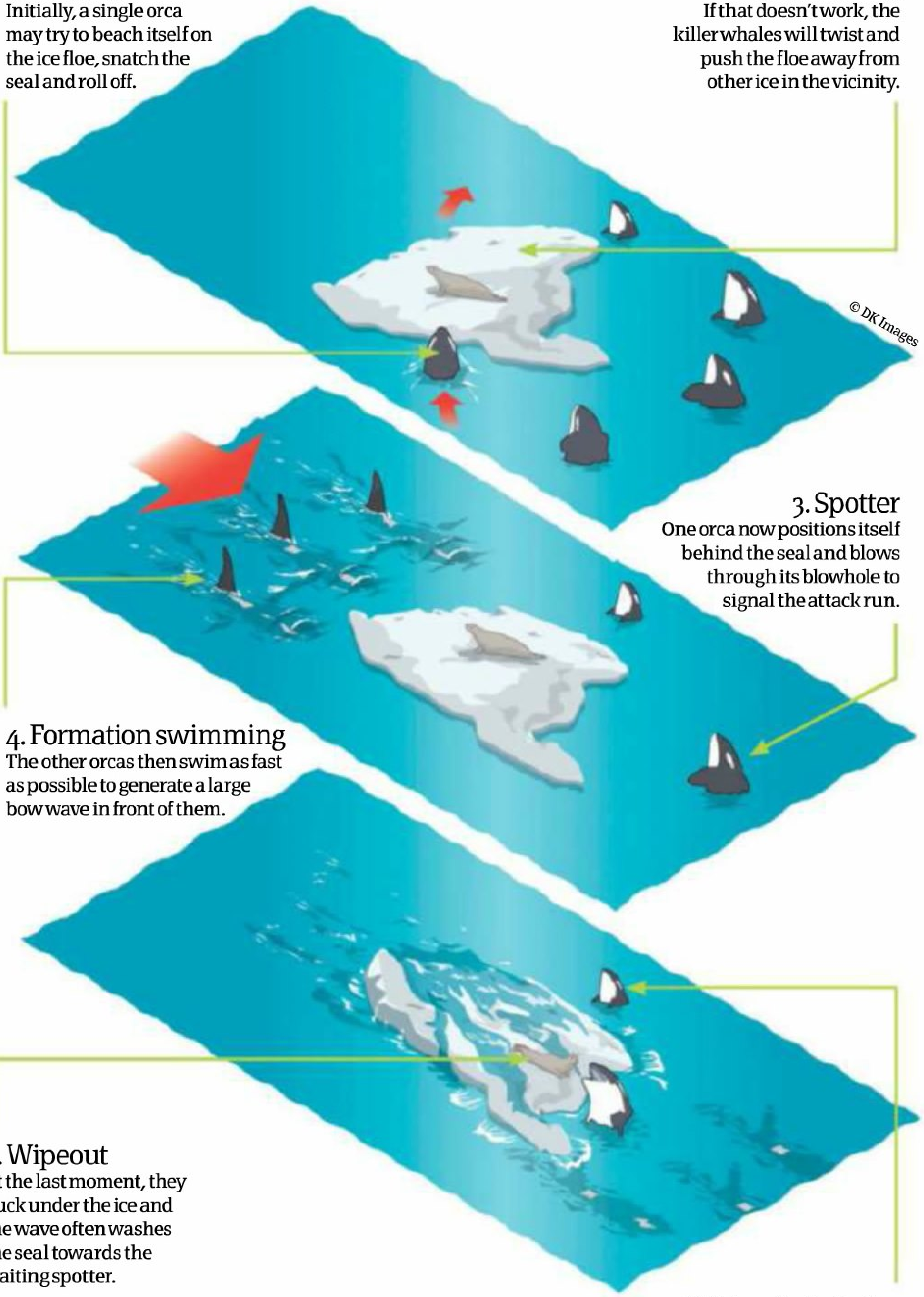
Pelvis
This tiny bone is all that remains of the ancestral pelvis, now that orcas have evolved for an aquatic life.

Tail fluke
Most of the thrust from the tail is generated on the upstroke of the two flukes, not the downstroke.

Median notch
Helps to reduce turbulence in the orca's wake, and thereby keep drag to a minimum.

© DK Images

Hunting as a pack


© DK Images

1. Lunging
Initially, a single orca may try to beach itself on the ice floe, snatch the seal and roll off.

2. Repositioning
If that doesn't work, the killer whales will twist and push the floe away from other ice in the vicinity.

3. Spotter
One orca now positions itself behind the seal and blows through its blowhole to signal the attack run.

4. Formation swimming
The other orcas then swim as fast as possible to generate a large bow wave in front of them.

5. Wipeout
At the last moment, they duck under the ice and the wave often washes the seal towards the waiting spotter.

6. School of whales
A young orca watches the co-ordinated attack to learn this hunting technique.

In April 2012 the first ever all-white orca – named Iceberg due to his 2m (6.6ft) dorsal fin – was spotted off the coast of eastern Russia

© E Lazareva/FEROP

Is keeping killer whales in captivity a good idea?

There are 42 orcas currently held in captivity in aquariums and sealife parks around the world. Since 1990, almost all of these have been born in captivity. Orcas put on an impressive show because of their huge size and striking appearance. But they are also extremely intelligent and they can be trained to perform spectacular jumps and a wide range of tricks.

Most zoo animals have longer life spans than in the wild but the reverse is true for orcas. Lack of company from other orcas and the limited size of their tank mean they rarely live beyond 25 years. The male orca's huge dorsal fin nearly always loses rigidity and flops over after a few years in captivity. This is a permanent structural change to the fin cartilage and may be due to insufficient exercise or too much time spent swimming at the surface.

How do owls catch prey?

The great grey owl lives in the taiga, a coniferous, snowy zone in the northern half of the planet that stretches from Alaska to Siberia

Discover what makes this nocturnal bird of prey such a superior predator

Owls have evolved a number of traits that make them masterful aerial hunters. As well as being a keen territorial predator, with an intimate knowledge of the local terrain, owls also have a number of physical characteristics that make them a formidable aerial assassin. Features include powerful talons, a sharp, hooked beak for rending flesh from bone, plus heightened senses for locating and homing in on prey.

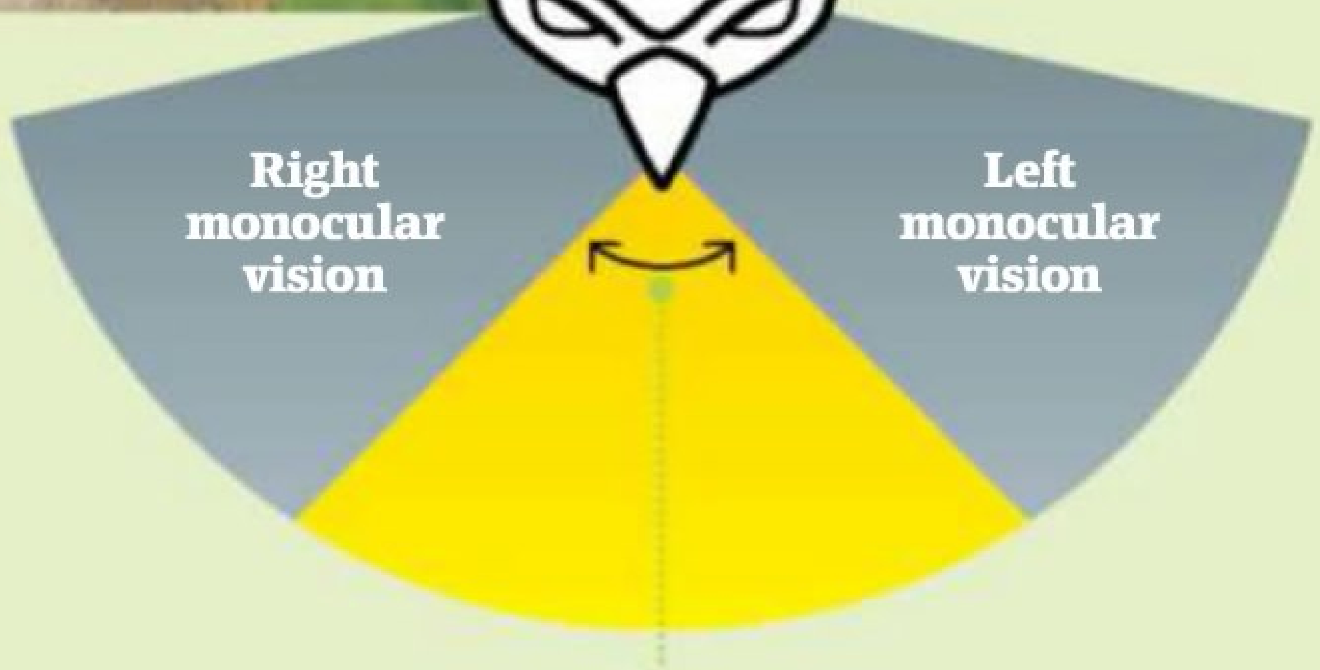
Super-sensitive hearing helps the owl pick up on the gentle rustling of small-footed prey such as birds, rodents and frogs far below. The extra-large disc-like shape of an owl's face with a ridge of feathers down the middle further improves hearing as sound waves are collected and channelled outwards towards the ears.

While we humans can hear sounds on a horizontal plane (ie we have the ability to tell whether a sound came from the left or right by turning our head in a particular direction to focus on the location of a sound) owls can hear things on a vertical plane. Species like the great horned owl, for example, have lopsided ears – with the left ear positioned slightly higher than the right, enabling them to accurately detect whether a sound originated from above or below.

Unlike the majority of other bird species, whose eyes are positioned on the sides of their heads, owls have front-facing eyes, giving them binocular vision and depth perception. This helps them get a fix on their quarry. They cannot, however, move their eyes in the sockets; instead they have the ability to turn their entire head some 270 degrees. This means they do not have to move the rest of their body to see what's going on behind them, which helps the birds to stay quiet. It's the ability to remain silent that gives an owl its greatest advantage when hunting. All these combined traits make the owl a silent, well camouflaged and highly effective hunting predator and among one of the sharpest birds in the sky.

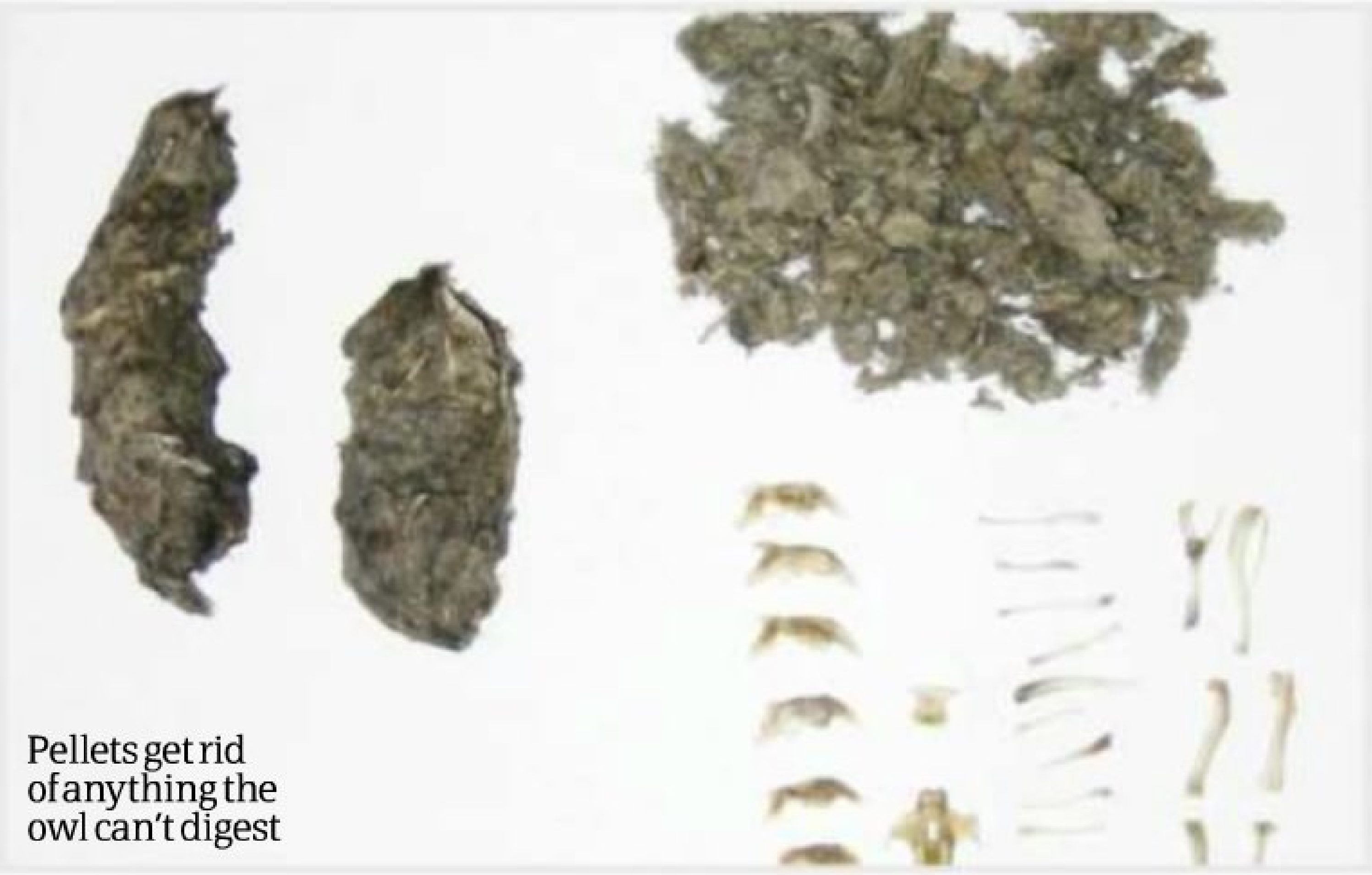
Seeing is believing

Owls have forward-facing eyes, like humans, and so this means they can see an object with both eyes at the same time. That is, their vision is binocular, as opposed to the monocular vision of most other birds whose eyes are located on the sides of their heads. As you can see from this diagram, owls have a wide field of view – around 110 degrees – but only about 70 degrees of this 110 are binocular.



Binocular vision (70 degrees)

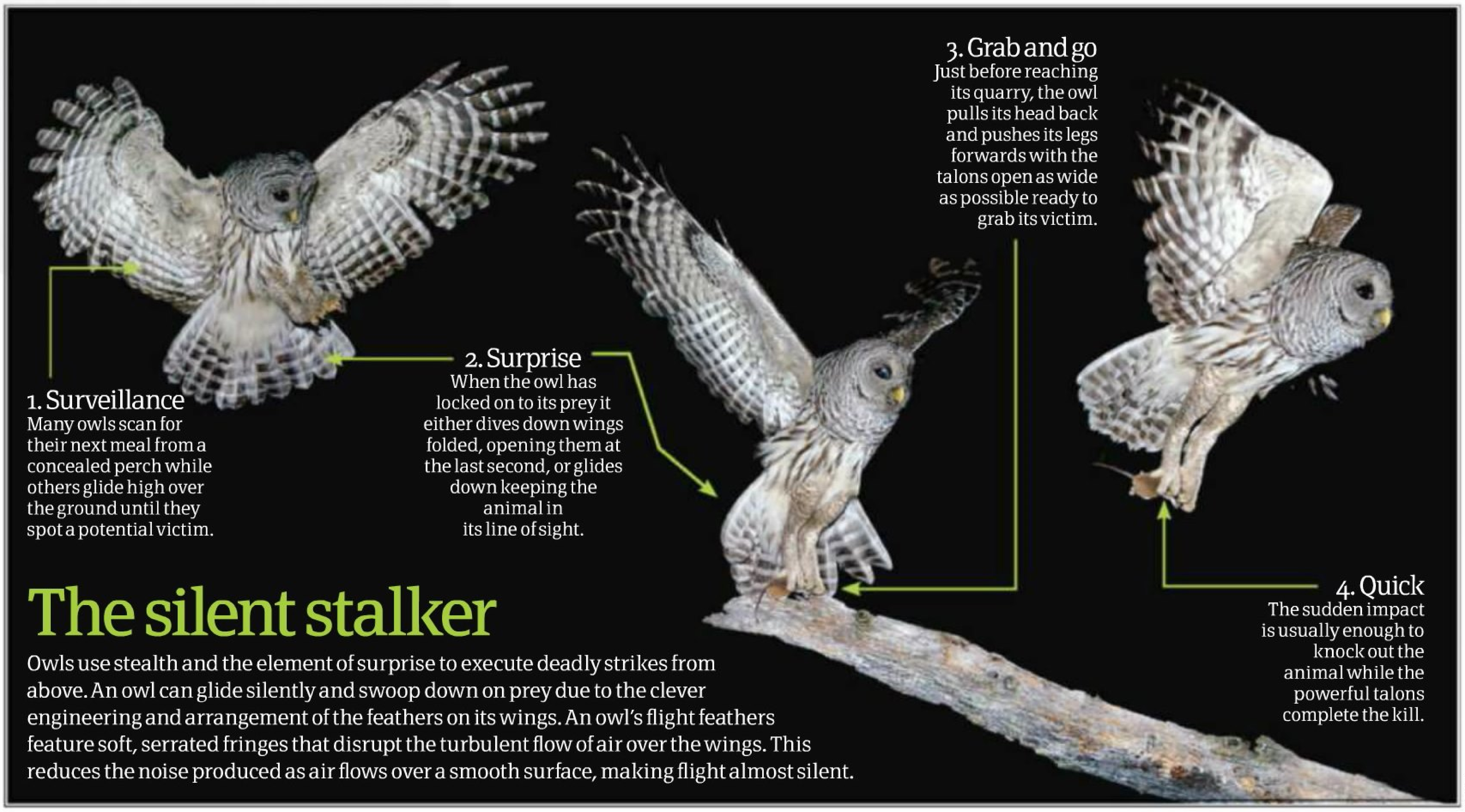
Owls have some of the best eyesight in the bird world. To put it into context, humans have an 180-degree field of vision, 140 degrees of which are binocular.



Pellets get rid of anything the owl can't digest

What are pellets?

You can discover a lot about what an owl eats from the pellets it spits out. These pellets contain the indigestible parts of an owl's diet. Birds of prey eat rodents and small birds. However, because owls don't have teeth and cannot chew their food, they have to swallow things whole – that includes any fur, bones, feathers, claws and teeth. While other birds have a special organ called a crop, which is used for storing food for digestion later, owls do not have one of these. Instead, when an owl consumes food, it passes into the muscular gizzard called the ventriculus, a kind of secondary stomach full of small stones. The stones help to grind up the digestible food (which includes muscle, skin and organs) and digestive enzymes and acids dissolve the food so it can pass into the intestines. The leftover rubbish, which can't be broken down, is squeezed by the muscles of the gizzard and compacted into a soft pellet to be expelled from the body after many hours. The owl cannot eat again until the pellet has been coughed up, or regurgitated.



1. Surveillance
Many owls scan for their next meal from a concealed perch while others glide high over the ground until they spot a potential victim.

2. Surprise
When the owl has locked on to its prey it either dives down wings folded, opening them at the last second, or glides down keeping the animal in its line of sight.

3. Grab and go
Just before reaching its quarry, the owl pulls its head back and pushes its legs forwards with the talons open as wide as possible ready to grab its victim.

4. Quick
The sudden impact is usually enough to knock out the animal while the powerful talons complete the kill.

The silent stalker

Owls use stealth and the element of surprise to execute deadly strikes from above. An owl can glide silently and swoop down on prey due to the clever engineering and arrangement of the feathers on its wings. An owl's flight feathers feature soft, serrated fringes that disrupt the turbulent flow of air over the wings. This reduces the noise produced as air flows over a smooth surface, making flight almost silent.

© SPL

What's inside horse hooves?

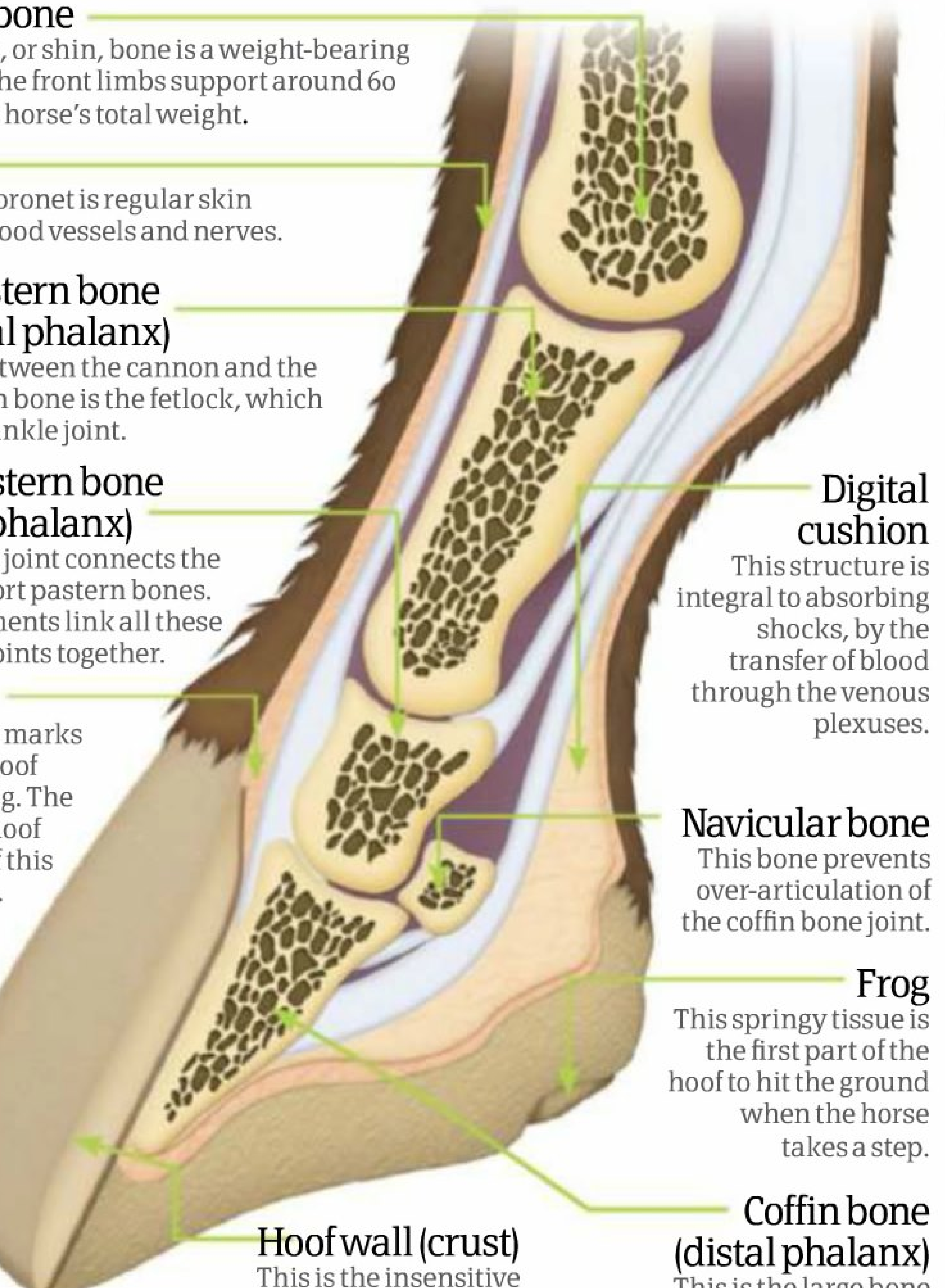
Discover the structure of a horse's foot and why fitting horseshoes doesn't cause pain

Horse hooves are the thick horny coverings that protect the end of the horse's leg and also provide shock absorbency. Horse hooves are made of a tough protein called keratin – the same stuff our nails and hair are made of. The keratin in a horse's hoof is layered in horizontal sheets, in order to add strength and minimise the extent of any damage that could split the hoof irreparably in the event of a crack.

Horses are digitigrade – ie they walk on their tiptoes – and therefore require a spongy pad situated beneath the heel on which to walk. While the outer wall of the hoof is insensitive – much like human hair and fingernails – the inner parts can feel pain. Therefore, when a farrier fits a horseshoe to the hoof, they do so by hammering the nails into only the outer wall of the hoof. Horseshoes – which are often made of steel these days – offer added shock absorbency as well as traction on the ground.

These curved metal bands come with between six and eight square nail holes through which the metal pins can be slotted. One by one, the nails are hammered into the hard, nerve-free outer wall of the hoof, securely fastening the shoe to the creature's hoof.

Horse hoof anatomy



Cannon bone
The cannon, or shin, bone is a weight-bearing structure. The front limbs support around 60 per cent of a horse's total weight.

Skin
Above the coronet is regular skin featuring blood vessels and nerves.

Long pastern bone (proximal phalanx)
The joint between the cannon and the long pastern bone is the fetlock, which is a kind of ankle joint.

Short pastern bone (middle phalanx)
The pastern joint connects the long and short pastern bones. Strong ligaments link all these bones and joints together.

Coronet
The coronet marks where the hoof meets the leg. The wall of the hoof grows out of this small bulge.

Hoof wall (crust)
This is the insensitive outer casing of the hoof, which never stops growing.

Digital cushion
This structure is integral to absorbing shocks, by the transfer of blood through the venous plexuses.

Navicular bone
This bone prevents over-articulation of the coffin bone joint.

Frog
This springy tissue is the first part of the hoof to hit the ground when the horse takes a step.

Coffin bone (distal phalanx)
This is the large bone inside the hoof. Many tendons and ligaments are attached to this.

Tissues in the stump de-differentiate themselves – ie they return to their embryonic 'become anything' state. The collection of cells from which the new limb grows is called the blastema

© Alamy

How do animals regenerate limbs?

Learn how some creatures have a natural ability to regrow certain body parts

One of nature's most intriguing biological miracles is the amazing ability of some creatures to regrow damaged or severed body parts. Animals including seastars, salamanders, planarians (flatworms), crabs and even some types of fish are all capable, to varying degrees, of body part regeneration, ranging from limbs to tails, and on to even eyes and internal organs.

The complicated process all starts with the clever cells we humans have when we are growing in the womb: namely stem cells. Embryonic stem cells are those that do not yet have a speciality – that is, they can potentially become any cell in the body, whether that's bone, muscle or nerve tissue.

Creatures that can regenerate brand-new body parts remodel themselves into their original physical form by reactivating the cells near the wound site and instructing them to behave like stem cells.

Some animals can retain bundles of these embryonic stem cells in their bodies, which – in the event of an unfortunate amputation – migrate to and proliferate around the newly created wound where they get straight to work rebuilding the missing or damaged body part, just as if it were a growing foetus.

> "Embryonic stem cells are those that do not yet have a speciality"

How does a spider construct its web?

The spinnerets in action, here being used to cocoon a victim

© Alamy

Learn how arachnids create a spiral web

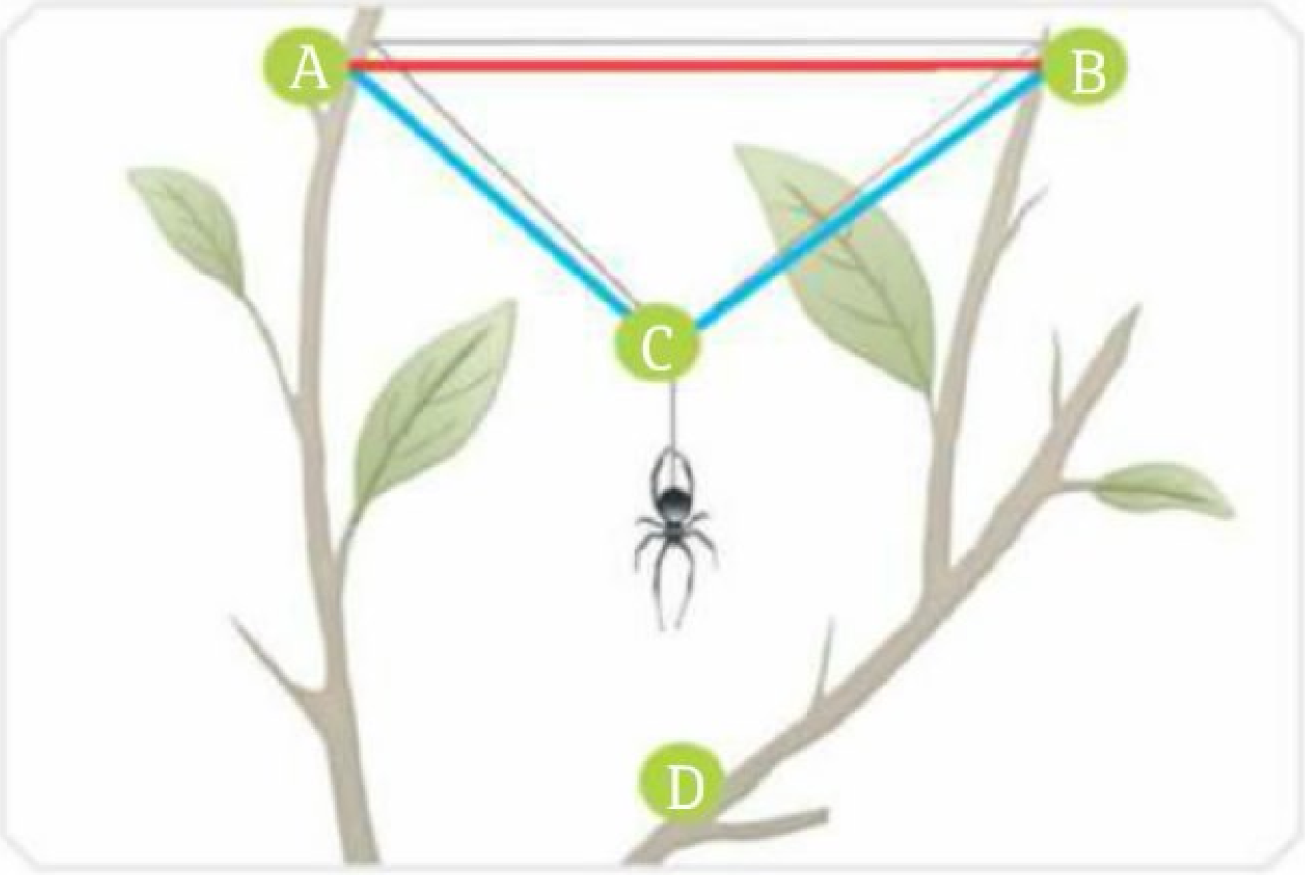
Building a spider web is a very complex process. Referring to the stages below, first the spider (at point A) dangles a length of sticky silk, which can be carried in the air until it sticks to an anchor point, such as a branch (see point B). Once the silk is attached to point B, the spider pulls it taut and fixes the original end to anchor point A, creating the 'bridge thread' (red). Now the spider fixes a second strand (blue) to point A and spins this while crossing the bridge. This thread is looser than the first and droops below the bridge thread. At point B the spider attaches this strand but doesn't pull it taut.

Next the spider travels back halfway along the now anchored loose thread (to point C; the web centre); the weight of the spider bows the thread into a V-shape, and from the bottom of the 'V', the spider attaches a third thread, which is spun as the arachnid descends to another branch (anchor point D). This turns the V-shape into a Y-shape, and creates another integral pathway. The spider continues to create more of these structural strands until a basic framework is in place.

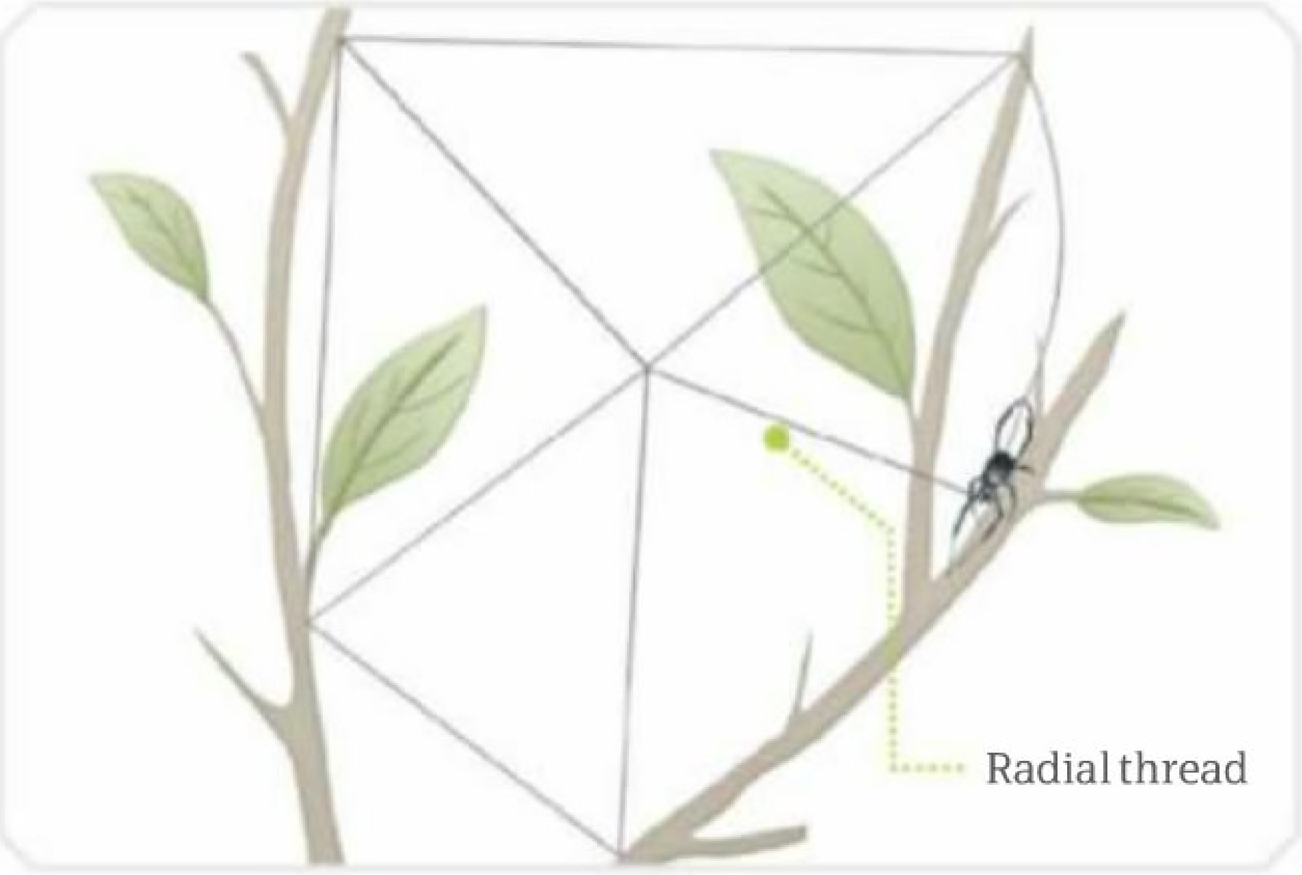
With the main frame lines in position, the spider adds radial threads from the centre to surrounding vegetation, much like the spokes of a wheel. These form the non-stick paths upon which the creature can safely navigate its trap.

Next the spider creates a silk spiral across the radial lines from the inside out. Using this as a template, it repeats this stage, except this time the threads are coated in bug-catching adhesive.

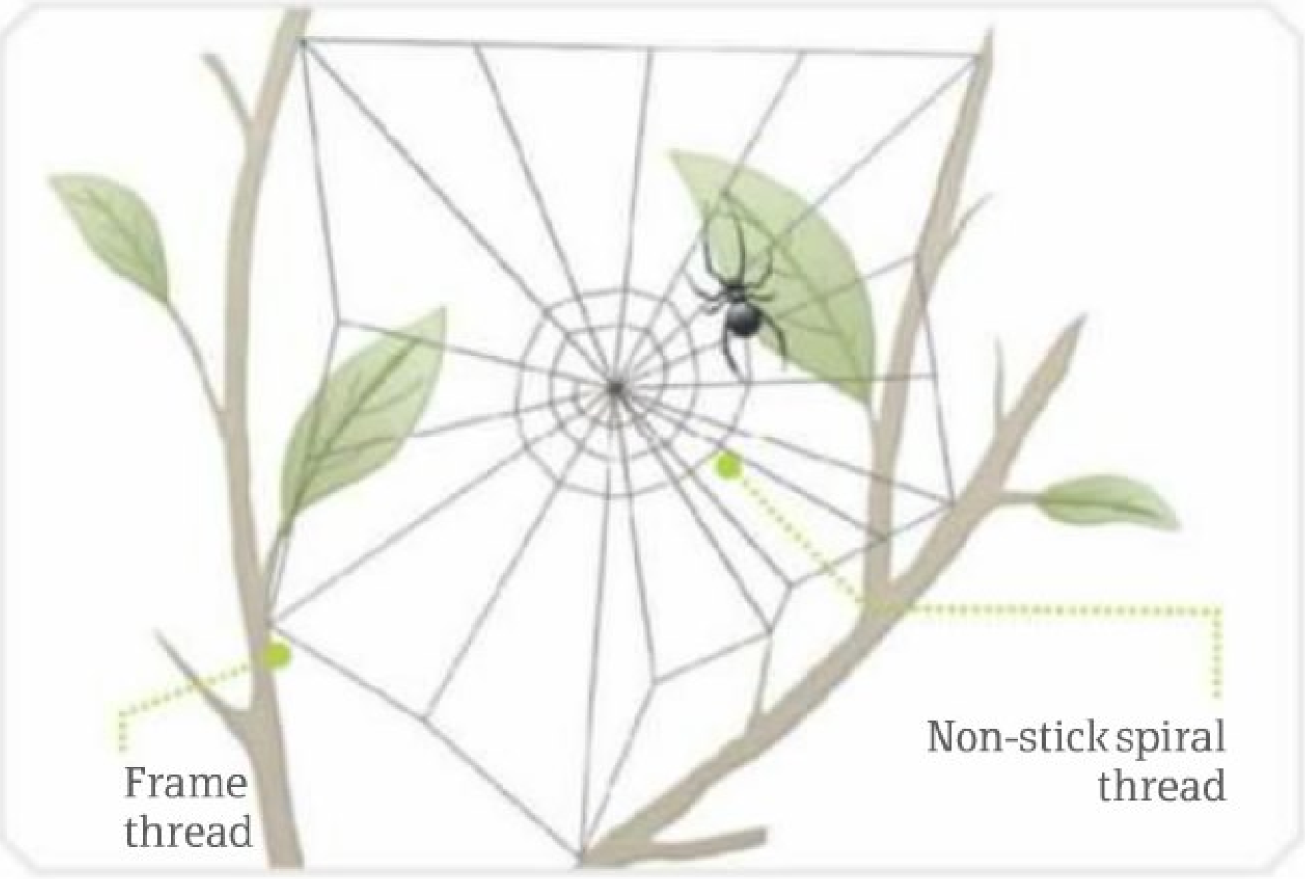
Stage 1: Creating a framework



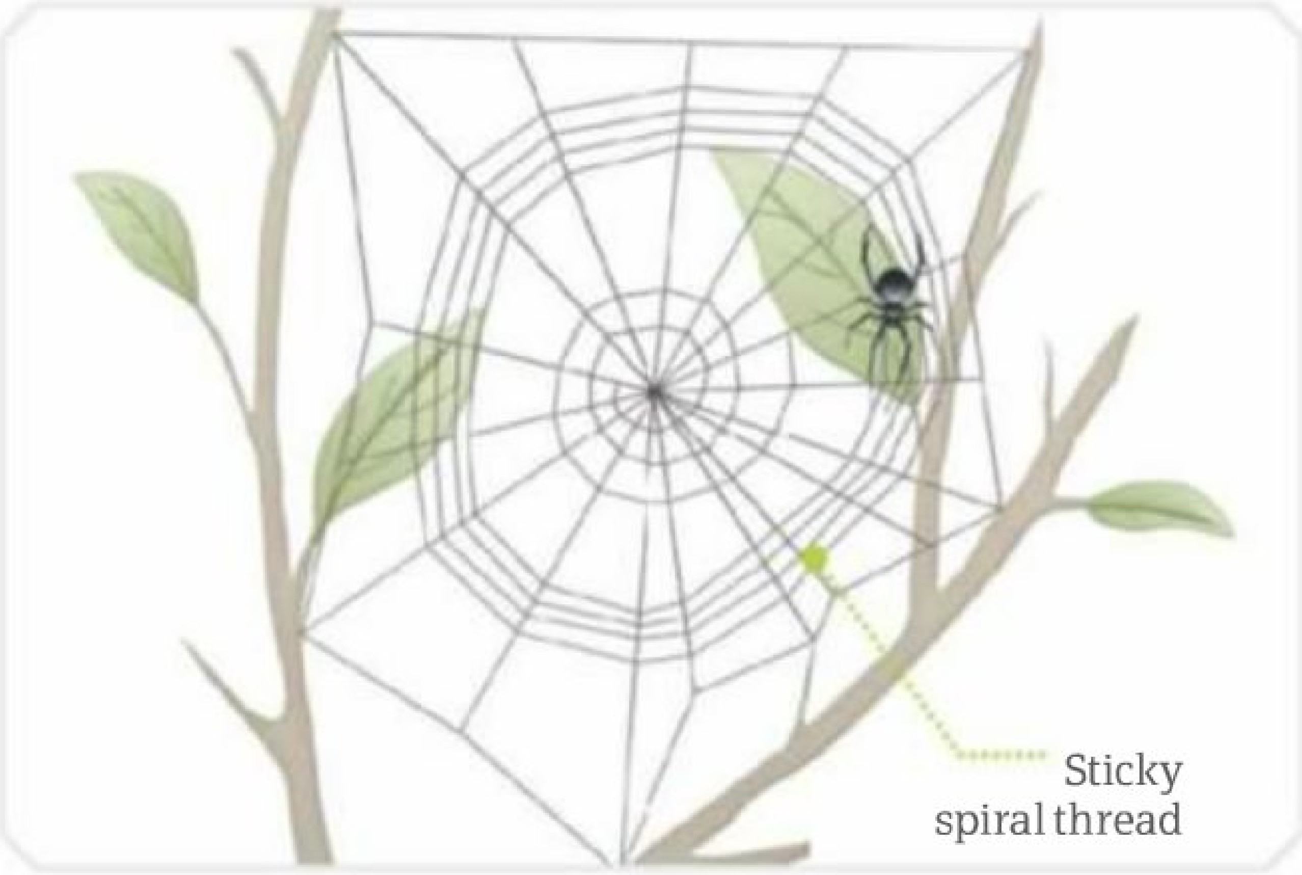
Stage 2: The orb takes shape



Stage 3: The spiral template



Stage 4: Setting the trap

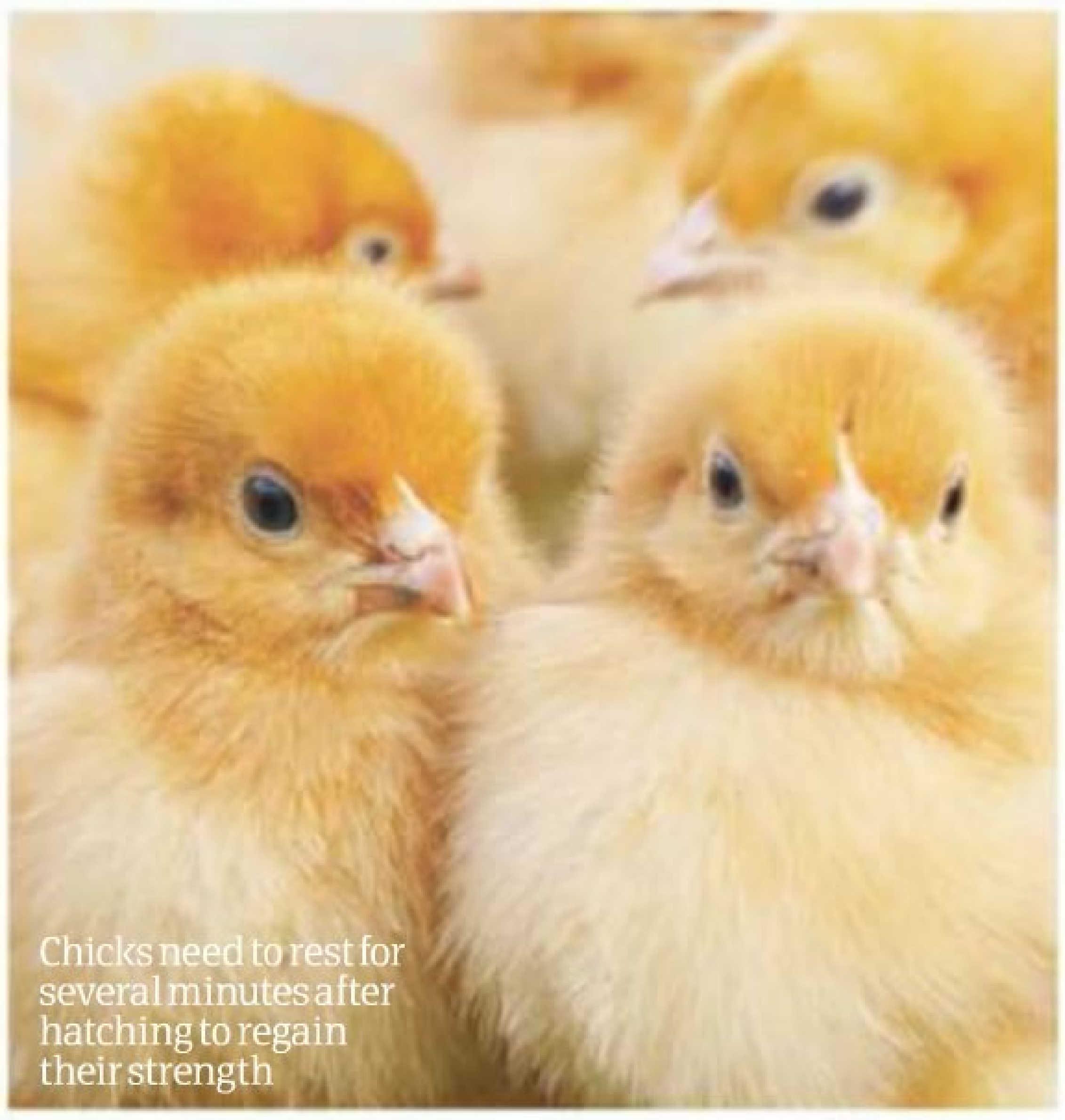


The science of silk

Spider silk is made of proteins called fibroins. It's very strong – in fact, weight for weight it's tougher than steel – yet also extremely elastic. These two characteristics, together, make for one unique substance in nature that the world's greatest material scientists have been trying to re-create artificially.

Silk is secreted as a liquid from the spider by the spinnerets, which are special glands located in the tip of the arachnid's abdomen. Upon contact with air the liquid instantly hardens to become a fine but strong silk. As the material is produced, the spider pulls it into long, thin threads using its legs.

The reason the spider itself does not become caught in its own web is that, first, it knows which sticky strands to avoid and, second, the adhesive hardens if the unwitting victim makes a sudden movement, but not with the gentle, considered movements of the spider.



Chicks need to rest for several minutes after hatching to regain their strength

How do chickens lay eggs?

The debate over which came first – the chicken or the egg – still rages. However, we can tell you how a chick emerges from an egg…

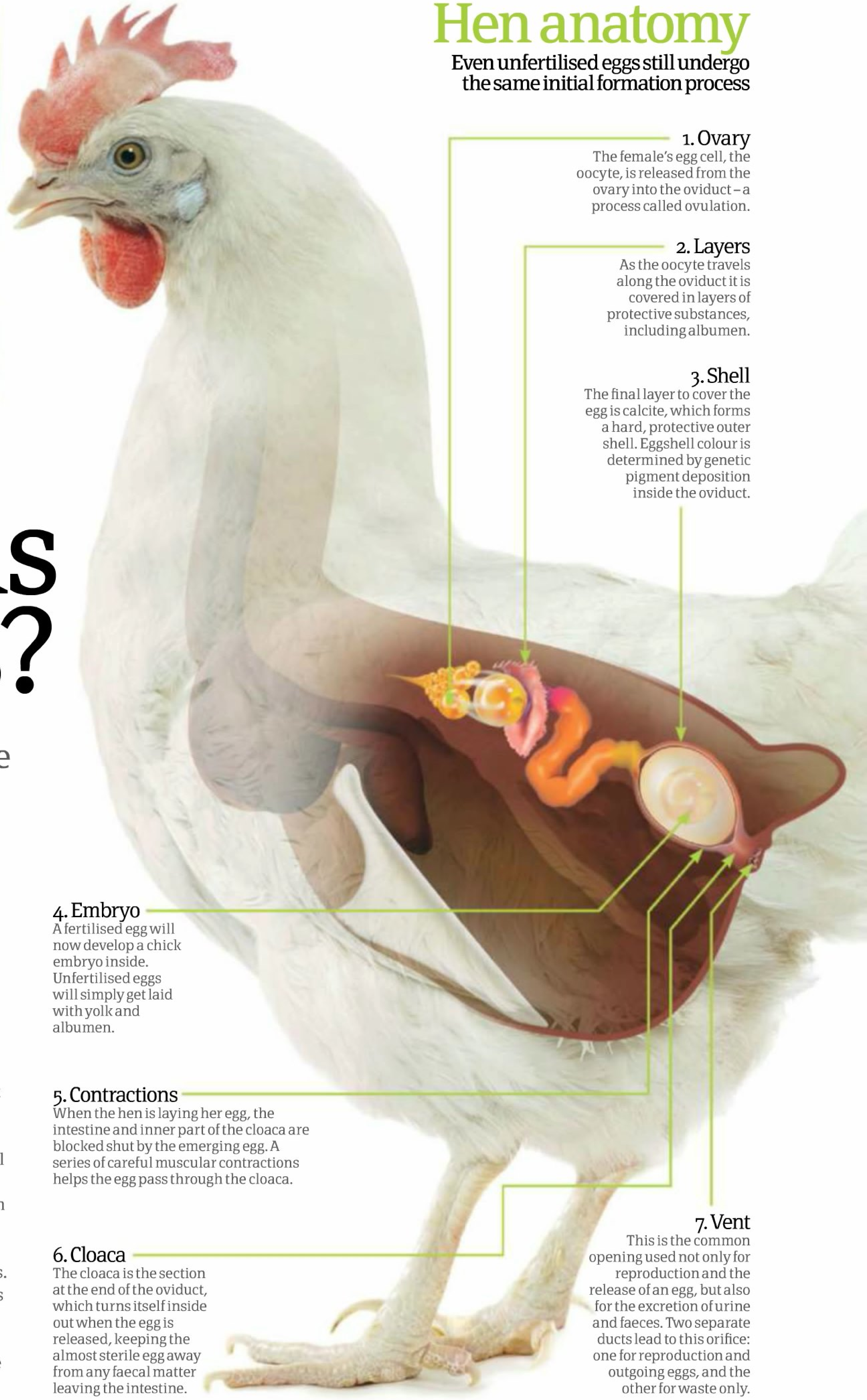
Hens lay no more than one egg per day as the process of laying an egg is governed by the presence of sunlight. The lack of natural light during the winter months means that even fewer eggs are laid during this time of the year. Humans can, however, 'trick' chickens into laying despite the limited sunlight by adding artificial light (such as a light bulb) to the coop.

The laying process starts when light entering the hen's eye activates a photosensitive gland (the pineal gland) positioned nearby. Once stimulated, this gland triggers a process that leads to the release of an egg, or oocyte, from the hen's ovary. An egg can still be laid whether or not it has been fertilised by a male, but only fertilised eggs can develop into chicks.

The orifice through which the egg leaves the hen is called the vent. Though this hole also forms the outlet for waste by-products (ie urine and faeces), there is a valve called the cloaca which separates the oviduct from the intestine.

Hen anatomy

Even unfertilised eggs still undergo the same initial formation process



1. Ovary
The female's egg cell, the oocyte, is released from the ovary into the oviduct – a process called ovulation.

2. Layers
As the oocyte travels along the oviduct it is covered in layers of protective substances, including albumen.

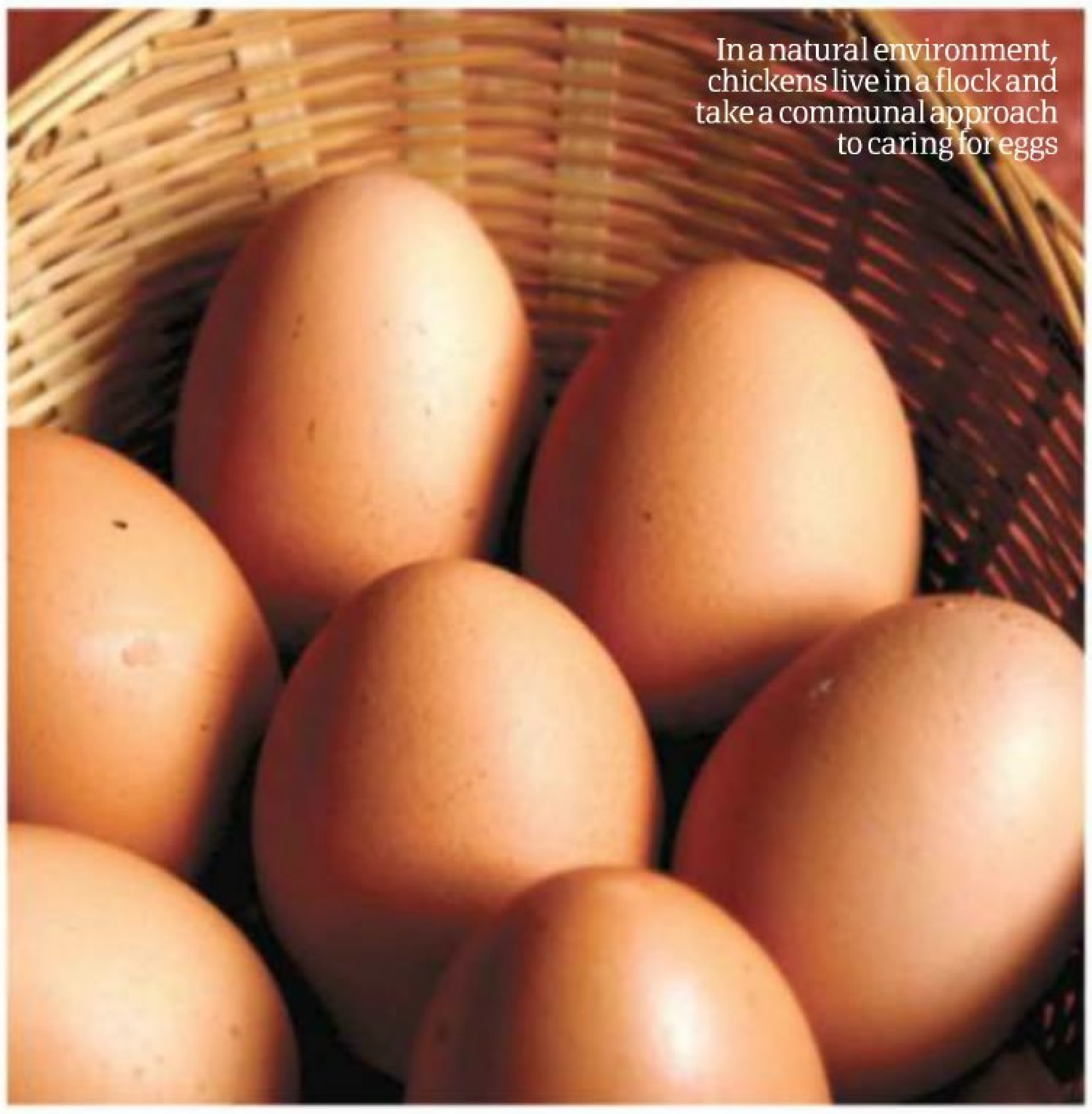
3. Shell
The final layer to cover the egg is calcite, which forms a hard, protective outer shell. Eggshell colour is determined by genetic pigment deposition inside the oviduct.

4. Embryo
A fertilised egg will now develop a chick embryo inside. Unfertilised eggs will simply get laid with yolk and albumen.

5. Contractions
When the hen is laying her egg, the intestine and inner part of the cloaca are blocked shut by the emerging egg. A series of careful muscular contractions helps the egg pass through the cloaca.

6. Cloaca
The cloaca is the section at the end of the oviduct, which turns itself inside out when the egg is released, keeping the almost sterile egg away from any faecal matter leaving the intestine.

7. Vent
This is the common opening used not only for reproduction and the release of an egg, but also for the excretion of urine and faeces. Two separate ducts lead to this orifice: one for reproduction and outgoing eggs, and the other for waste only.



In a natural environment, chickens live in a flock and take a communal approach to caring for eggs

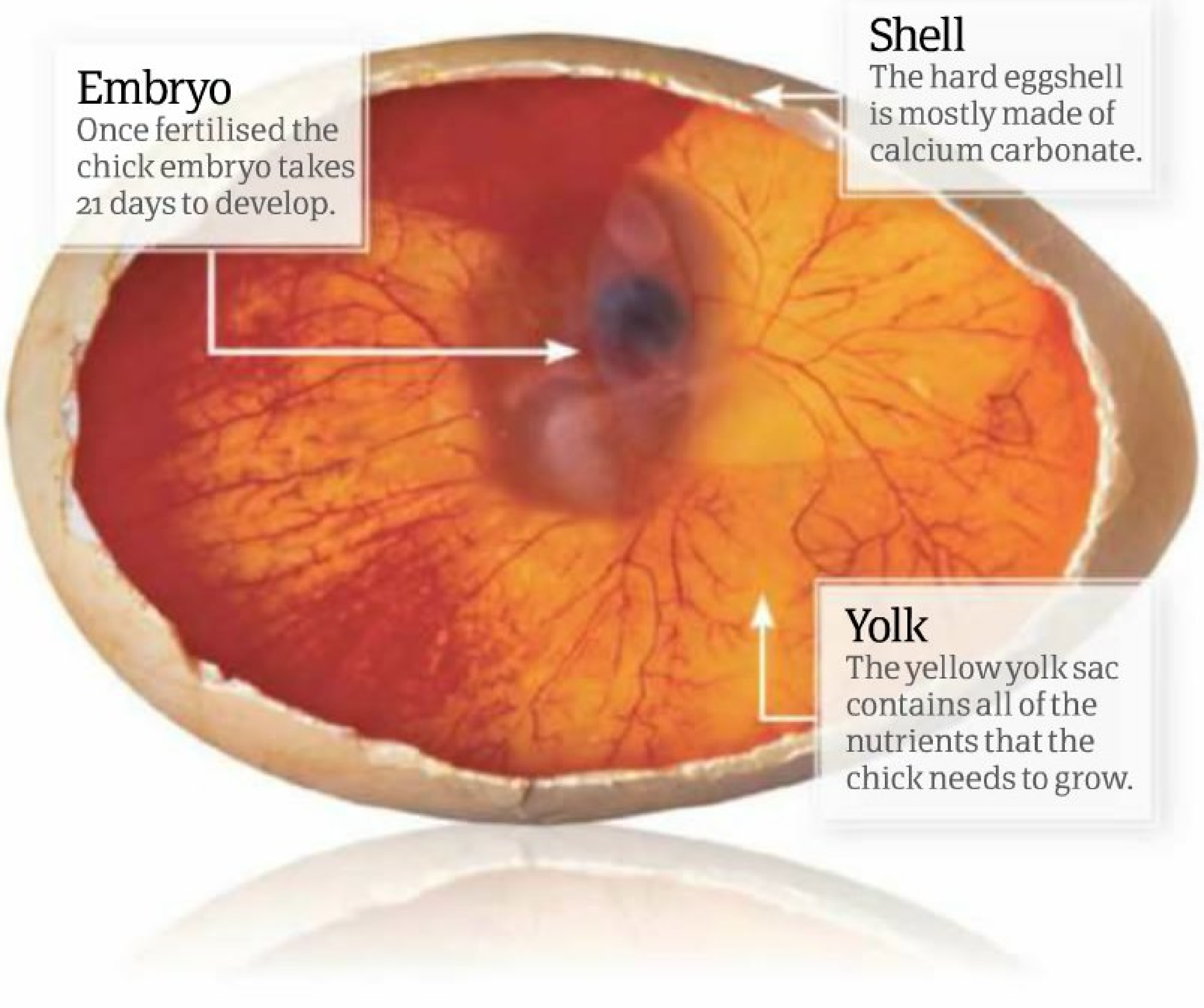
Feeling broody?

A hen will keep laying around one egg per day until she has a dozen eggs – also known as a clutch. If the eggs are collected by humans each day, however, the hen will continue to lay eggs in an effort to produce a clutch of 12. Once an egg has been laid, the hen will leave the nest, causing the embryo to cool and suspending its development. As long as the nest temperature stays warm, an embryo can remain suspended for up to two weeks until the hen has managed to lay a full clutch.

Once she has produced a clutch of eggs the hen will stop laying and start brooding, which involves sitting on the eggs for three weeks while the embryos develop. This means the eggs should all hatch at the same time.

Inside the egg

What goes on under the shell?



Embryo
Once fertilised the chick embryo takes 21 days to develop.

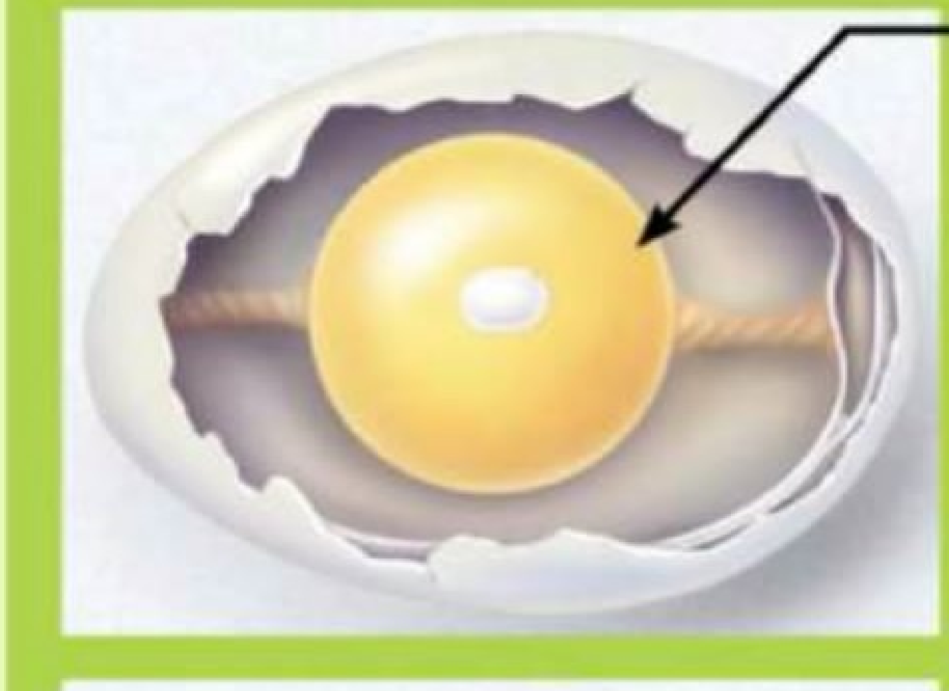
Shell
The hard eggshell is mostly made of calcium carbonate.

Yolk
The yellow yolk sac contains all of the nutrients that the chick needs to grow.

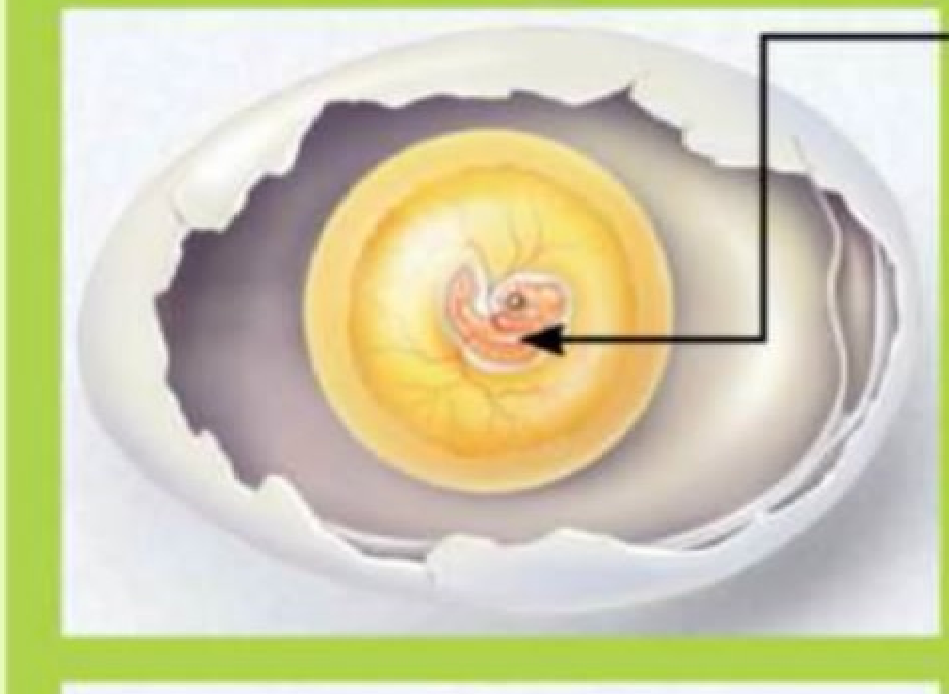
Embryo development

How a fertilised yolk transforms into a chick

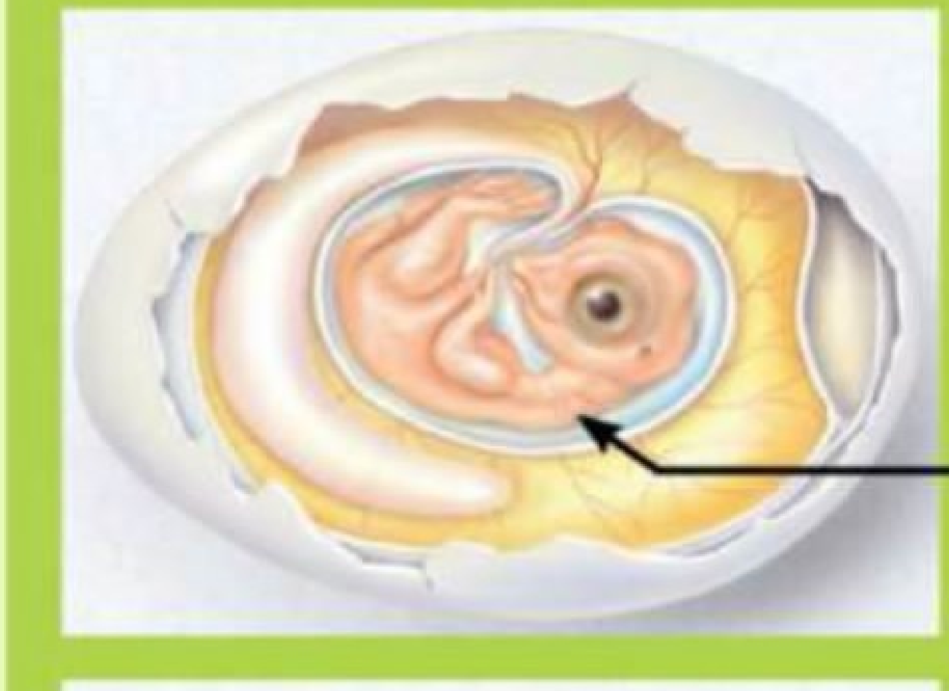
The chick starts out as a single cell that divides and forms a hollow disc on the surface of the yolk. This yolk is then released into an oviduct tube. As it travels down the oviduct it builds up a number of layers, including a vitelline membrane surrounding the yolk, and two layers of viscous white albumen divided by a structural fibrous layer. Lower in the oviduct tube the eggshell layer develops around the yolk. When the egg is expelled from the body so begins the following 21-day period of embryonic development…



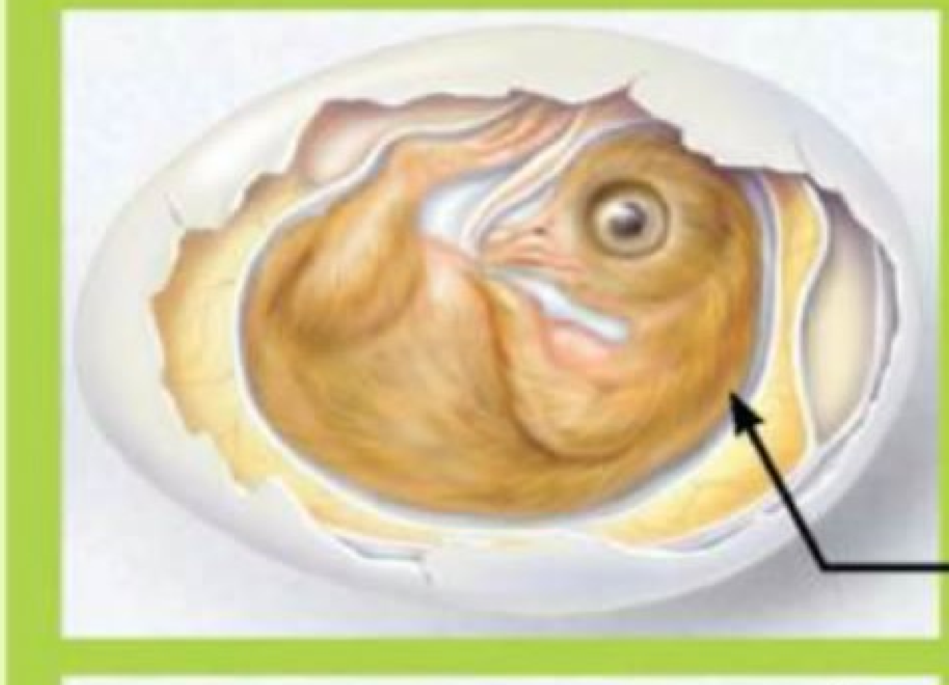
DAY 1: Yolk
The fertilised yolk contains all the nutrients needed to sustain a developing embryo. By the time a fertilised egg is laid, many cells have already started to divide in the germinal disc on the surface of the yolk. A structure called a chalaza made of albumen located inside the egg holds the yolk in place, anchoring it to either end of the shell and protecting it. Over time the chalaza gets twisted as the yolk moves around.



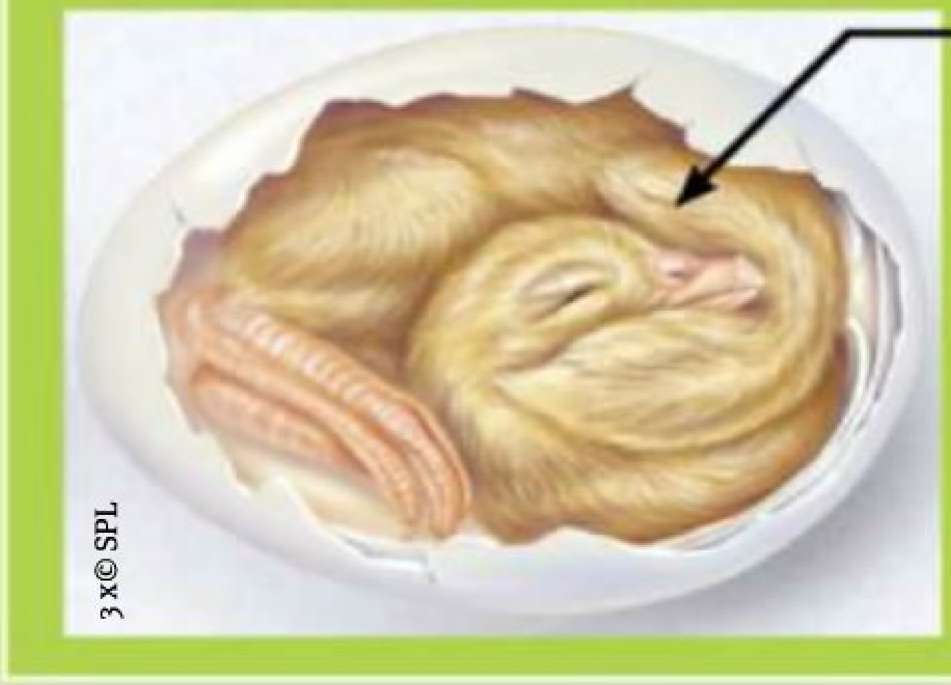
DAY 4: Heart
After a couple of days the heart will have formed and begun to beat independently. At this stage the head, eyes and even the beginnings of its legs will have begun to form, and by day four the embryo's reproductive organs will start to develop. The thin membrane separating the albumen from the eggshell grows as the contents of the egg shrinks, creating a tiny pocket of air. This air space will enable the chick to start to breathe.



DAY 10: Skeleton
After ten days the embryo will still be featherless but it will start to draw calcium from the shell in order to grow its tiny skeleton, enabling the bones of the legs and spine to develop. The claws and beak will also begin to form.



DAY 16: Preparing to hatch
The leg and wing bones will become increasingly advanced and strong. Internal organs are now almost fully developed too. By now the beak will also be upturned towards the pocket of air inside the shell, ready to break through the soft inner membrane and take its first breath.



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DAY 20: Breakthrough
Between day 16 and hatching, the chick's beak will have penetrated the inner membrane to access the air inside the shell and the lungs will have begun to function. The yolk sac has now been absorbed into the chick's body cavity. The chick pecks at the outer shell using a horny projection on its beak called the egg tooth. The second stage involves chipping away at the shell, until it can push the top of the shell off with its head.

What is inside a plant cell?

Discover how these tiny living structures function

Without the plant kingdom, life on Earth would be a very different prospect. This huge and diverse group of living organisms not only nourishes the vast majority of animal life with tasty, nutritious roughage, but it also replenishes our atmosphere with enough oxygen to keep us living and breathing. Quite simply, life on Earth depends on plants. There are a number of characteristics that make all living things 'alive'. For instance, they require food for growth and development; they respond and adapt to their surrounding environments; they have a life cycle of growth, reproduction and death; and, importantly, they contain cells.

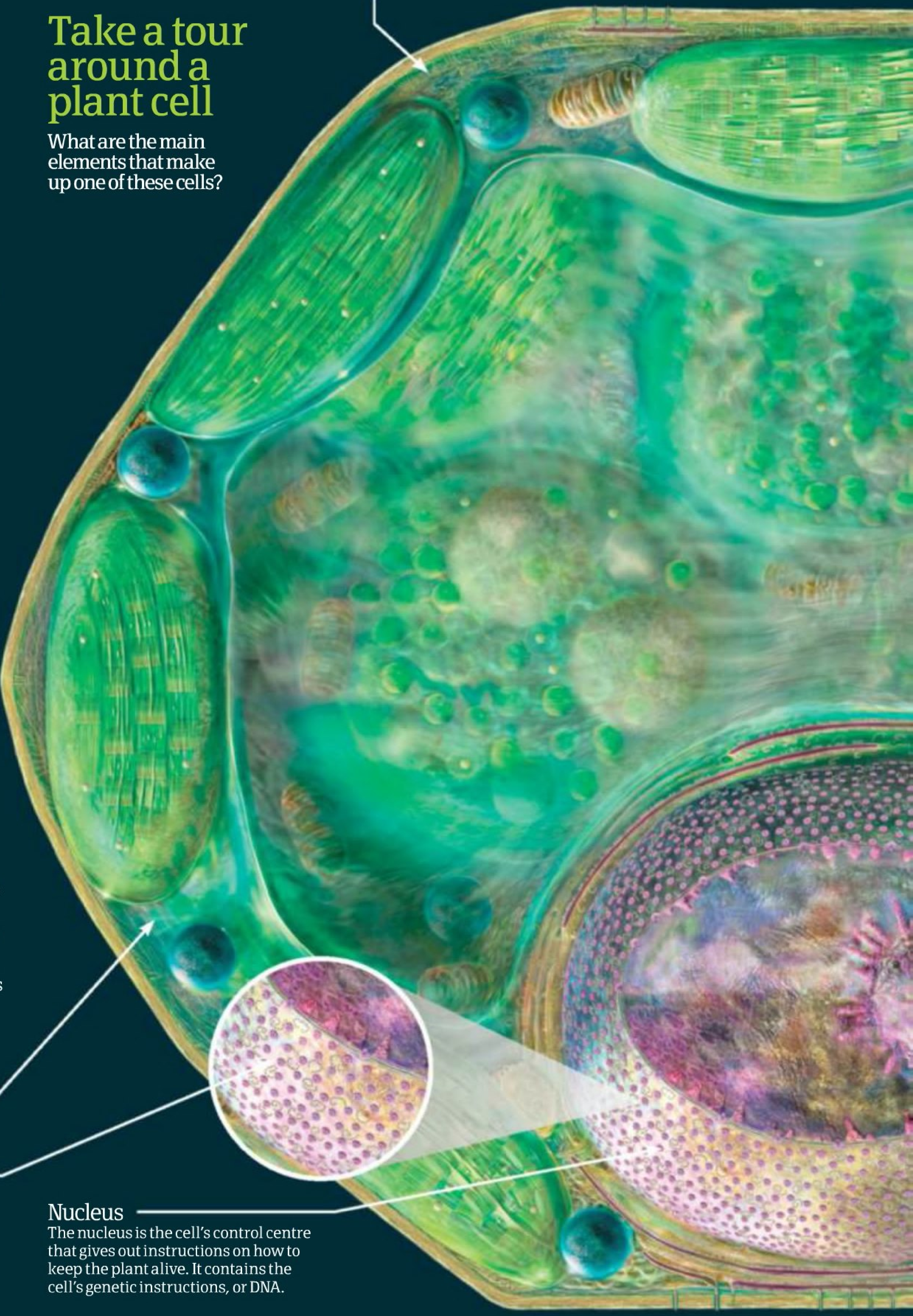
Discovered by Robert Hooke in the 1650s, plant cells are the building blocks of all plant life. Just like animal cells, they are eukaryotic, which means they contain a nucleus – a structure that acts as the cell's 'brain' or command centre. Found in the nucleus is the plant's genetic information, which is used to inform the rest of the cell which functions to carry out.

Everything inside the cell is contained within a thin, semi-permeable lining called the plasma membrane. Inside this membrane is a sea of cytoplasm, a gelatinous substance in which all the other parts of the plant cell are found – most of which have specialised functions. These 'expert' structures have dedicated roles and are known as organelles, or 'mini organs'. Surrounding the plasma membrane is a rigid outer cell wall made from a fibrous substance called cellulose.

Another characteristic of a plant cell is its large vacuole. This is an area filled with fluid and gas and it accounts for most of a cell's mass. The vacuole swells with fluid to help maintain a cell's shape. The tough cell wall is strong enough to withstand this increased pressure and ensures this organic 'balloon' doesn't burst.

Take a tour around a plant cell

What are the main elements that make up one of these cells?

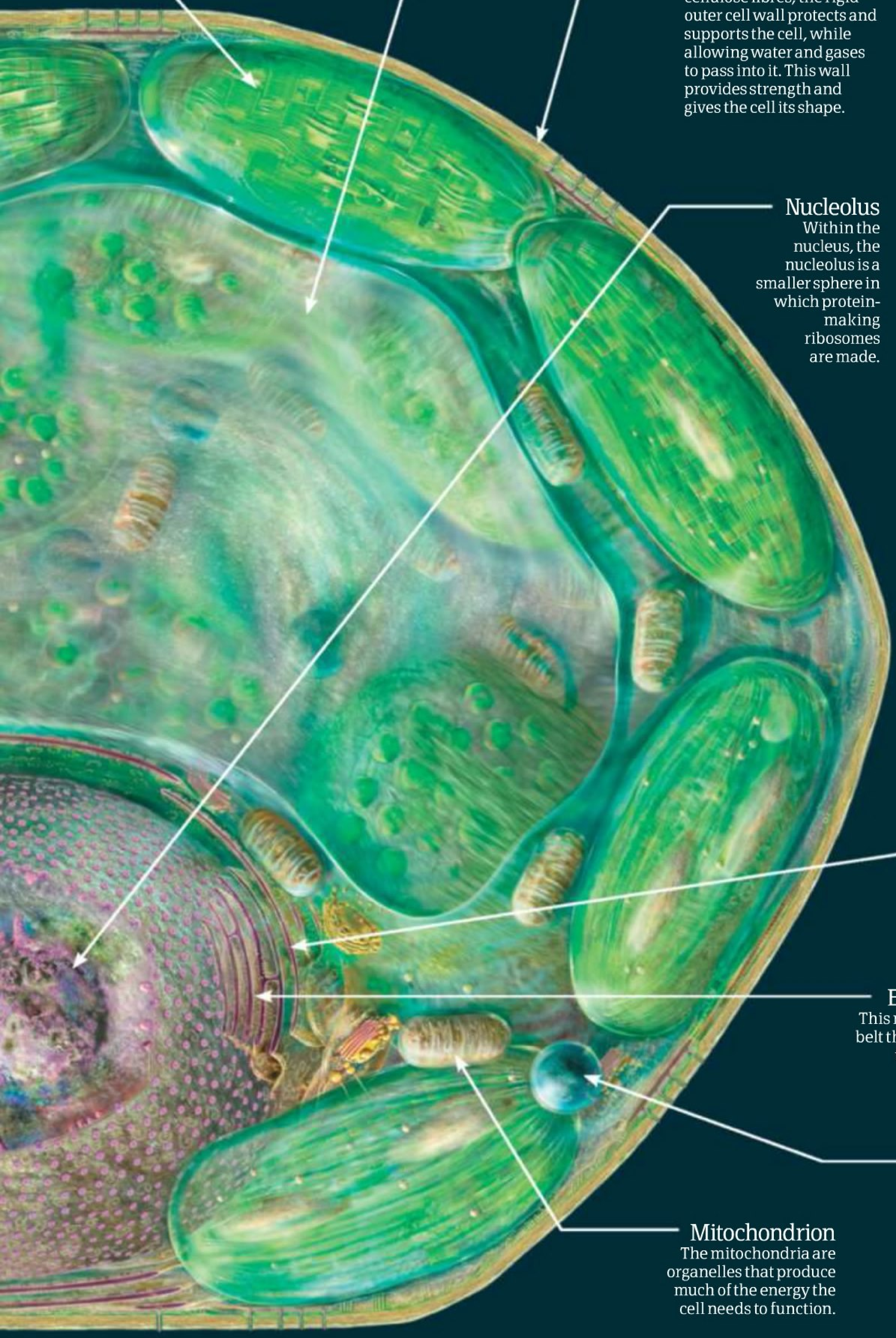


Cell membrane
The cell, or plasma, membrane is the layer that covers the cytoplasm and separates the cell from its external environment. It controls all substances passing in and out of the cell.

Cytoplasm
Cytoplasm is the jelly-like substance inside the cell in which energy-producing chemical reactions occur. The cytoplasm fills the space between the cell membrane and the nucleus.

Ribosome
Found either floating in the cytoplasm or attached to the endoplasmic reticulum, ribosomes are the tiny structures that manufacture proteins.

Nucleus
The nucleus is the cell's control centre that gives out instructions on how to keep the plant alive. It contains the cell's genetic instructions, or DNA.



Chloroplast
Chloroplasts are effectively like solar panels that capture the Sun's energy and use it to make food for the plant – a process called photosynthesis. Inside a chloroplast is chlorophyll, the pigment which gives most plants their green colouring. Chlorophyll is essential for photosynthesis as it absorbs the sunlight to produce glucose.

Vacuole
The large vacuole is a kind of storage area for water and waste gases. It helps to keep the cell plump and turgid.

Cell wall
Made of indigestible cellulose fibres, the rigid outer cell wall protects and supports the cell, while allowing water and gases to pass into it. This wall provides strength and gives the cell its shape.

Nucleolus
Within the nucleus, the nucleolus is a smaller sphere in which protein-making ribosomes are made.

Golgi apparatus
Also a kind of organelle, a Golgi body processes and packages proteins ready for transport outside the cell or to other parts within the cell.

Endoplasmic reticulum
This membrane acts like a conveyor belt that transports proteins around the plant cell interior aswell as outside the cell wall.

Peroxisome
Peroxisomes are the organelles that aid photosynthesis. They contain enzymes that break down toxins and remove waste from the cell.

Mitochondrion
The mitochondria are organelles that produce much of the energy the cell needs to function.

© SPL

Plant cells vs animal cells

As we've mentioned already, there are many similarities between plant and animal cells. However, there are also several key differences. For example, animal cells are bigger and less regular in shape and size than those of plants, which are generally regimented in appearance. Take a look at the main structures in a plant cell that are absent in animal cells.

Cell wall

While both animal and plant cells have a thin cell membrane that controls what goes in and out, plants differ in that they also have a cell wall made of cellulose. This rigid outer wall enables the plant to hold a lot of moisture under pressure without popping, while also providing essential structural integrity. The contents of an animal cell, meanwhile, are held by the cell membrane alone. Animals tend to rely on endo- and exo-skeletons for support.

Single large vacuole

Plant cells also contain a single, extra-large vacuole, which takes up most of the space in the cell and keeps it plump and turgid. Some animal cells do contain vacuoles, but they are always much smaller and never take up this much space.

Chloroplasts

Plants manufacture their own food (glucose) from sunlight, water and carbon dioxide, but humans and animals must *absorb* food obtained from plants and other living creatures. The difference is that plant cells contain chloroplasts – the structures that contain the green, sunlight-absorbing chlorophyll pigment – in which photosynthesis can take place.

> "There are several key differences between animal and plant cells"

Can honey go bad?

Honey is the only food that does not go off – indeed, honey found in King Tutankhamun's tomb was still edible. It has a high sugar content and antibiotic properties that act as preservatives. Over time honey becomes cloudy as the sugar crystallises, but this does not spoil it and you can dissolve the sugar by heating it gently. If moisture gets into the honey, though, yeast can grow, ferment and spoil the foodstuff, but so long as it is kept tightly sealed, honey can last indefinitely.

It's fair to say that fleas aren't a dog's best friend…

What are fleas?

Fleas are small (2-3 millimetre/ 0.08-0.1-inch) red-brown wingless insects that feed on the blood of mammals and birds. They are compressed side to side so that they can move through fur and feathers easily and have long legs that let them jump 100 times their height. They can survive for months without food and their young can live in our carpets and bedding. Flea bites are itchy and can cause allergic reactions. Fleas can also carry diseases such as bubonic plague and myxomatosis.

Why can't an elephant jump?

As the world's largest land animal, weighing several tons, elephants are simply too heavy to jump. Their bone structure prevents them from bending their legs enough to push themselves off the ground. Elephants do not have natural predators so they did not need to be able to jump to improve their chances of survival. Elephants do not even like standing on two legs, although they can be trained to do that.

How do red and grey colour squirrels differ?

There are two red squirrel species in the northern hemisphere. North American red squirrels are small and have a red-brown back, a black side stripe and white belly, while Eurasian red squirrels are large with a red to grey grizzled coat and white belly, or are melanistic (black). The grey squirrel also is large and is a well-known invasive species. Grey squirrels are either a grey-brown grizzled colour with a light belly or melanistic. The two species can also differ in bone and tooth structure, but these features are difficult to examine in live animals.

Why do dogs like chasing things you have thrown?

Chasing down a stick or toy brings out the inner wolf in man's best friend

Dog are descended from wolves that chased after mammals and birds for food, so the chase instinct is already present from birth. But domestication has also created a link between dogs and humans. Dogs actively seek play opportunities with us because they want our approval. Consider the question from the other perspective: why do we like throwing things for dogs to chase? We like it because the dog enjoys it and we find its happiness rewarding. Dog and owner are engaged in a mutual back-scratching exercise, where the pleasure of one reinforces the pleasure of the other in a cycle.

Why do rabbits have long ears?

The rabbit's long ears serve two main functions. The first is so that they can catch sound coming from any direction. Rabbits can move their ears independently so they can hear in two directions at once. The second is that they give off heat from their body through a vast network of blood vessels to keep the bunny cool, since these animals can't sweat or pant. However not all rabbits have big ears – some domesticated breeds like the Netherland Dwarf have short ears that serve the same purpose.

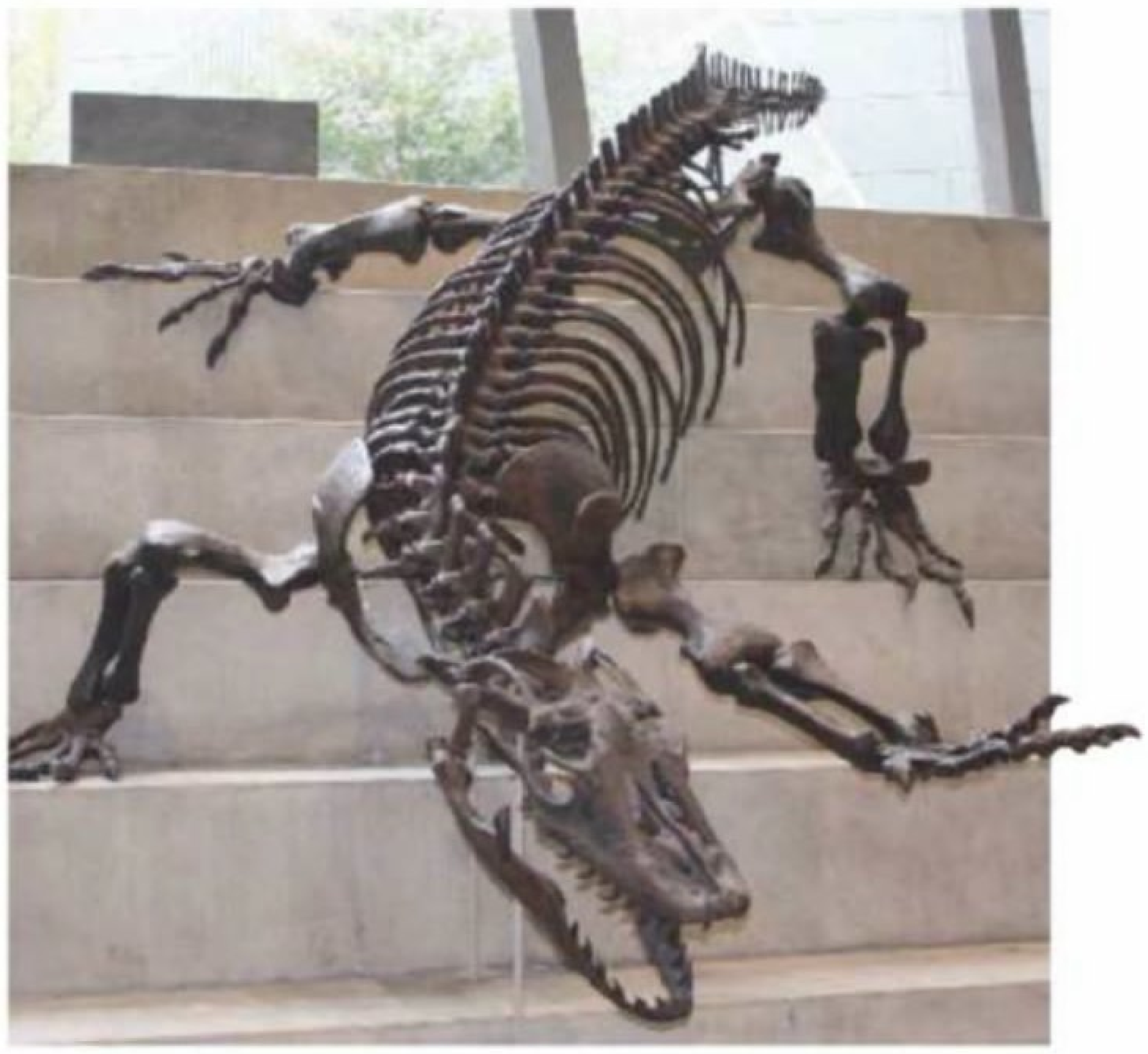
Why do flamingos stand on one leg?

For a long time, this was a mystery. Then in 2009 two American psychologists studied a captive flamingo colony and concluded: it's about conserving heat. Although flamingos are native to tropical climates, they spend most of their time standing in cold water and their long legs mean lots of exposure to it. Tucking one leg up helps to regulate their body temperature. They usually vary which leg is up and, when the weather is warmer, they're more likely to stand on two legs.

Trees flattened by the Tunguska explosion in Siberia

What's the biggest lizard ever to live?

If you were tempted to think 'some kind of dinosaur', then think again – dinosaurs were similar to reptiles but weren't lizards. The answer is varanus priscus, or megalania, a terrestrial lizard native to Australia that became extinct over 40,000 years ago. Although most experts agree megalania was the biggest ever, opinion is divided on just how big it was, with estimates varying between 4.5-7 metres (14.7-23 feet). This is because no complete skeletons have been found, although fossil fragments do suggest megalania was heavily built with a mouthful of sharp, serrated teeth. The world's largest living lizard is a distant relative of megalania, the Komodo dragon, which is a kind of monitor lizard.



* * *

Why is Costa Rica's geography so good for growing coffee?

Coffea arabica produces the finest arabica coffee beans. This shrub flourishes in Costa Rica because of the fertile soil, altitude and climate. Most Costa Rican coffee is grown in the highland valley region, Meseta Central, between 800 and 1,500 metres (2,600-4,900 feet). Here the soil is acidic and mineral-enriched by lava and ash spewed from volcanoes.

There are also two distinct seasons. The rainy season from May to November has cool, wet afternoons that promote coffee growth, and sunny mornings. During the dry harvest season, meanwhile – from around December to March – hot, sunny days aid coffee bean ripening.

Why do albino animals have red eyes?

Eye colour is determined primarily by the brown pigment melanin. Dark eyes have lots of melanin in the iris. Blue eyes only have melanin in a layer on the back surface; this absorbs long wavelengths of light and blue wavelengths get scattered back by the colourless protein fibres. Albinos don't even have melanin on the back surface, so the iris is translucent. The red colour is the haemoglobin in the capillaries at the back of the eye. Albino animals find bright light uncomfortable as their irises can't block as much light as non-albino ones.

How thick is the ice in the Antarctic?

The thickness of Antarctic ice is tough to measure because it is literally freezing on top and hard to reach at the bottom. The underside of the thinnest sheets is estimated to be less than 200 metres (656 feet) from the surface. Where the ice is thickest, though, you would have to drill down more than ten times that distance to reach the base. Scientists have long thought that Antarctic ice builds up largely through snow forming layers like those in sedimentary rocks. Recently, however, they have discovered that ice sheets might also grow through a process of water thawing and refreezing to the bottom.

Why do bees die after they sting us?

Most bees and wasps don't die after they sting us. The standard stinger design is smooth for puncturing the skin of other insects and it can be easily withdrawn and reused. But the honeybee, uniquely, has evolved a strongly barbed stinger as a defence against vertebrates. The bee doesn't just push the stinger into you – the barbs on either side of the central stylus act as ratchets that move back and forth to pull the stylus ever deeper. The elastic layers of your skin trap the barbs so when you brush the bee off, the stinger tears free, along with the venom gland and part of the digestive tract. The bee dies from this huge rupture, but the muscles in the stinger continue to work, pumping venom into the wound. The abdominal juices also act as a pheromone signal to other bees to join the attack. This suicide strategy results in a much more painful sting and is the best way to protect the hive. Unlike workers, queen honeybees have smooth stingers for multiple attacks. So the next time you're stung by a bee, think of what it's sacrificed to sting you.

Why do Persian cats have flat faces?

Not all Persian cats do have flat faces. The traditional, or doll-faced Persian, actually has a muzzle. In the late-Fifties, some cat fanciers decided a spontaneous mutation was a desirable trait, and began breeding Persians to have shorter and shorter muzzles until they had high noses and flat faces. This ultra-typed Persian cat became the breed standard according to the Cat Fanciers' Association. At its most extreme, a Persian cat with these features runs the risk of having deformed tear ducts and perpetually runny eyes, so some are calling for a return to the traditional breed.

What's the deepest hole we've ever dug?

The record for subsurface drilling is held by the Kola Superdeep Borehole in NW Russia. The scientific project reached 12,262 metres (40,230 feet) in 1989 before 180-degree-Celsius (356-degree-Fahrenheit) temperatures forced it to stop. The trouble with drilling to the Earth's core is not just the tough rock, crystal and eventually molten metal you'll encounter, but the rapidly increasing pressure, friction and heat. At around 1.5 million metres (4.9 million feet), temperatures would exceed 300 degrees Celsius (572 degrees Fahrenheit) – more than any drill-bit can cope with. Even then, we would still be over 4,500 kilometres (2,800 miles) from the inner core. So it's no good trying to drill our way into the Earth's core as we probably will never have tools capable to do this.

How do deer know it's rutting season?

Rutting season has evolved to ensure that young deer are born in spring when there is more new grass available for lactating mothers. This means the timing of the rut is different, depending on the gestation period of each species. But the trigger is the same: shortening daylight hours in autumn. Special cells in the eye of deer that aren't used for vision – called retinal light-sensitive ganglion cells – measure the length of daylight hours. This is relayed to the suprachiasmatic nucleus located in the brain. When the autumn days get short enough, it prompts the release of the appropriate hormones in males so they start competing for mating rights. This is a another animal kingdom wonder that aids the growth and perpetuation of this species.

A recent study suggests that a peacock's plumage doesn't up its chances of finding a mate

Why do peacocks have such unusual feathers?

The standard explanation, first posited by Charles Darwin, is that the peacock is advertising to the peahen what a good mate he will make. Peahens choose the males with the most impressive tails because it demonstrates that they are healthy and strong enough to drag such an encumbrance through the jungle, and also because the peahen wants to produce sons that will have big tails because then they will be successful in attracting mates themselves. This theory was recently challenged after a seven-year study in Japan found that large tails didn't make peacocks more successful in finding a mate. But that research has been criticised for ignoring colour and eyespot density. Therefore, Darwin's consensus that the peacock tail is a result of sexual selection still stands till date.

Do other mammals have different 'typical' blood pressures as compared to humans?

Since blood pressure is partially dependent on height and weight, as well as genes, the answer is most definitely yes. Despite recommended levels, even different humans have a range of what is 'typical'. A minimum blood pressure is needed to keep large vessels from collapsing, so the larger the animal (and therefore the blood vessels), the higher the blood pressure needs to be. While dogs and cats have similar ranges to human beings, elephants have a much higher average blood pressure to keep their much larger vessels open. While a 'normal' value in human beings might be considered to be 120mmHg (millimetres of mercury), in an elephant 180mmHg is average. To counter this high blood pressure, elephants have much lower resting heart rates.

> "Elephants have a higher average blood pressure to keep their larger vessels open"

Why do sloths generally hang upside down?

Sloths eat leaves with very little nutritional value. In fact, it takes up to a month for their food to digest. To compensate, they have a metabolic rate about half that of other mammals their size. Since they can't run away from predators or fight them off easily, they hide instead. Hanging below branches makes them less visible to harpy eagles and their claws can grip the branch without using any energy – indeed, sloths won't fall from a tree even if they're shot! Sloths spend so much time upside down that their fur lies the opposite way to most mammals, growing from the paws up to the body.

Can we eat ostrich eggs?

Not only can you eat them but they are delicious, surprisingly healthy and available online or even in certain supermarkets. Ostrich eggs contain more magnesium and iron, a lot less cholesterol and a little less saturated fat than the equivalent serving of chicken eggs. They provide less vitamin A and E and less zinc, but that's not really the problem with adding them to a balanced diet – it's the practicality. Ostrich eggs typically weigh around 1.4 kilograms (three pounds), the equivalent of two dozen chicken eggs. They also take up to 90 minutes to hard boil and, at 2,000-plus calories per egg, will need 15 very peckish adults to finish. Oh, and you'll probably need a chisel or electric drill to break into the ostrich shell too!

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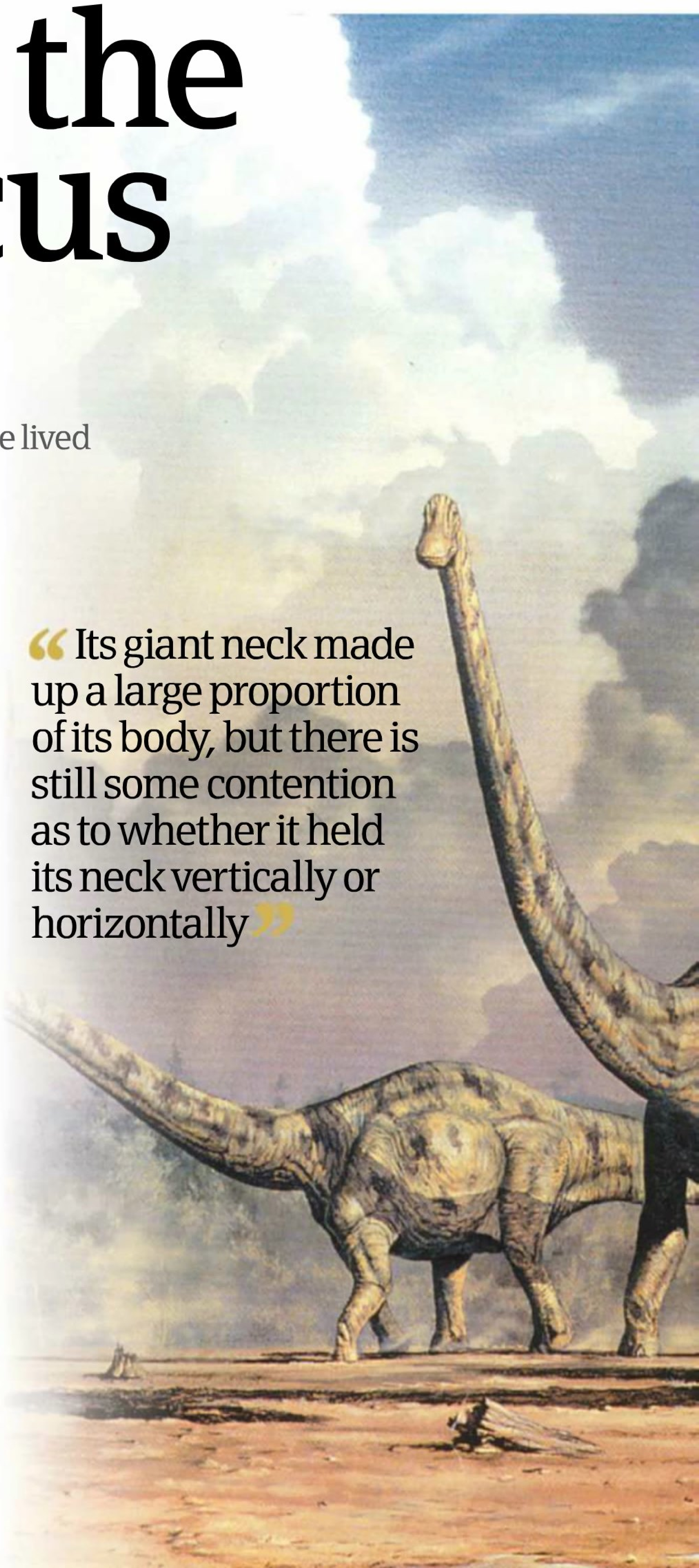
How did the diplodocus survive?

We find out how this mighty dinosaur once lived

Diplodocus is one of the most famous dinosaurs. It belonged to the group known as the sauropodomorphs and was around in the Late Jurassic period – specifically the Kimmeridgian and Tithonian eras roughly 154-150 million years ago. It reached sizes of up to 25 metres (82 feet) in length and was predominantly found in what is now North America. There were four species of diplodocus, with the largest of these being seismosaurus, which essentially translates to 'ground shaker'.

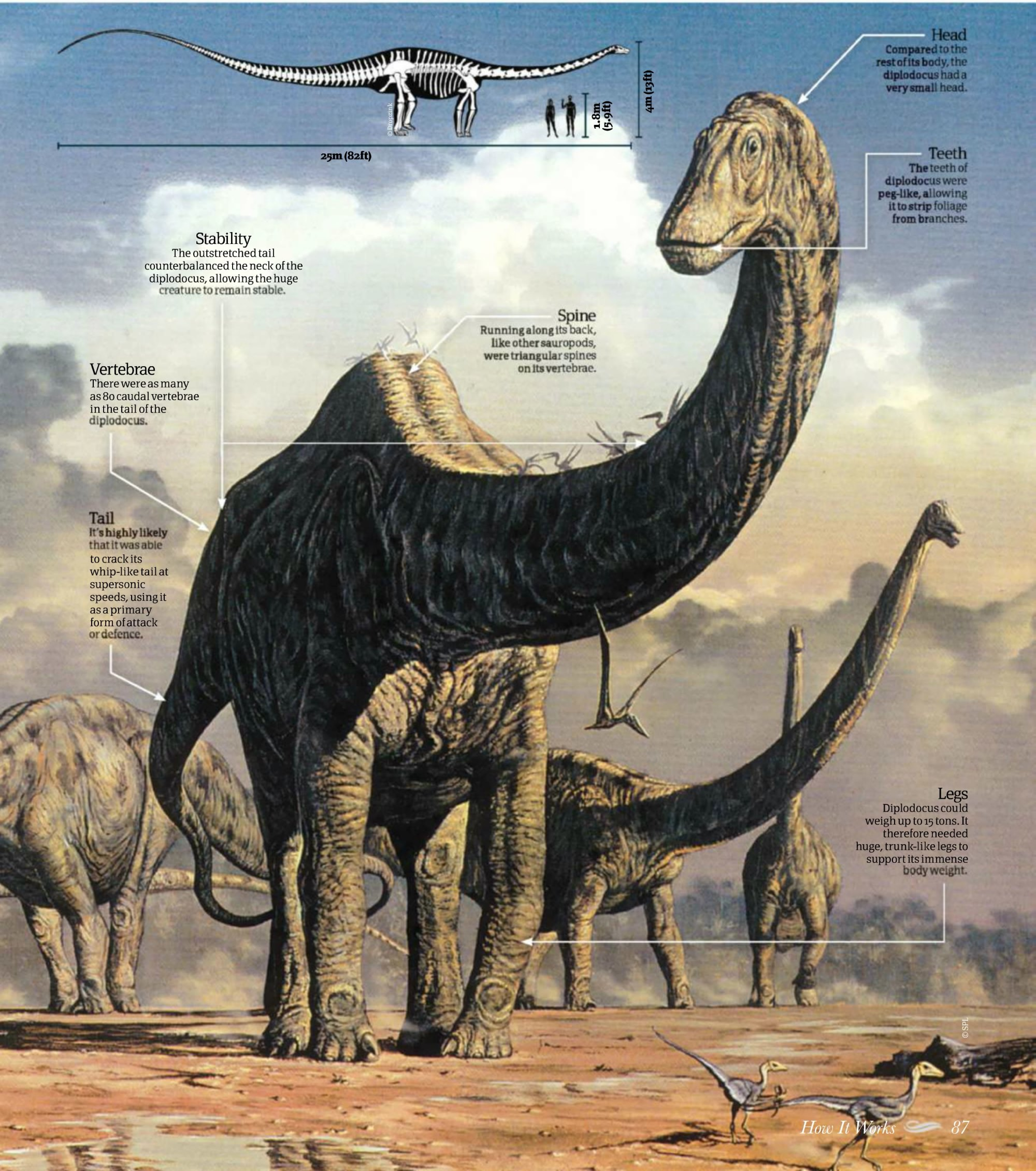
Diplodocus was part of the diplodocid family, sharing the same characteristic of having 15 neck vertebrae, short forelimbs compared to the rest of its body and a whip-like tail. Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally. Its rectangular skull contained huge eye sockets and nasal chambers, in addition to a long flat jawline and a small space for its comparatively little brain. Studies of its teeth suggest that diplodocus fed using what is known as branch stripping, where the branch of a tree is grasped in a creature's jaw and then pulled sharply up or down, tearing off foliage as it goes.

For its time, diplodocus was the largest dinosaur around. It was later eclipsed by other sauropods, but it roamed the tallest for at least a few million years. Numerous diplodocus bones have been found and studied by palaeontologists, providing an insight into how these giant dinosaurs were able to support themselves and generally how they lived.



> “Its giant neck made up a large proportion of its body, but there is still some contention as to whether it held its neck vertically or horizontally”

Diplodocus feet are believed to have been fleshy and cushioned by thick pads, much like those of elephants



Head
Compared to the rest of its body, the diplodocus had a very small head.

Teeth
The teeth of diplodocus were peg-like, allowing it to strip foliage from branches.

Stability
The outstretched tail counterbalanced the neck of the diplodocus, allowing the huge creature to remain stable.

Spine
Running along its back, like other sauropods, were triangular spines on its vertebrae.

Vertebrae
There were as many as 80 caudal vertebrae in the tail of the diplodocus.

Tail
It's highly likely that it was able to crack its whip-like tail at supersonic speeds, using it as a primary form of attack or defence.

Legs
Diplodocus could weigh up to 15 tons. It therefore needed huge, trunk-like legs to support its immense body weight.

© SPL

What was inside Tutankhamun's tomb?

Houses of Eternity were the final resting place of the pharaohs, including the most famous young ruler of Egypt, but how was the Boy King's burial site discovered and what historic riches were stored inside?

The world's greatest archaeological discovery was revealed when the tomb of Tutankhamun was opened by Howard Carter back in November 1922. Tutankhamun's grave was hewn during Egypt's 18th dynasty – by this time, the embalmers had perfected the art of mummification, and craftsmen, the art of tomb building. They cut the burial chambers with simple tools like wooden hammers and copper chisels. The interior was decorated with religious and magical inscriptions that were believed to empower the dead.

The body of Tutankhamun was buried in the Valley of the Kings near modern-day Luxor. The Valley was protected by a sacred mountain that seemed to swallow the setting Sun. In antiquity, this strange and atmospheric burial ground was shrouded in mystery; the craftsmen who worked there were separated from society and established in a remote desert town.

Secrecy was essential to the prevention of ancient tomb robbery, for many individuals risked life and limb in order to plunder the resting places of their royal ancestors. The tomb, known as a House of Eternity, contained unimaginable riches. Inevitably, as time passed, most of the royal tombs were looted by treasure hunters. Fortunately, the tomb of Tutankhamun survived detection, and over time it was forgotten.

Inside the funeral chambers, a plethora of grave goods had survived. These treasures included great golden shrines and magnificent coffins; on a smaller scale, Carter found caskets of the king's linen clothing – these included tunics that still bore rich bands of embroidery, while among the pharaoh's family heirlooms was a lock of his grandmother's hair. All finds, from the funerary mask to the floral garlands found on Tutankhamun's mummy, are equally invaluable to our understanding of the life of this enigmatic young ruler.

Child of the Sun

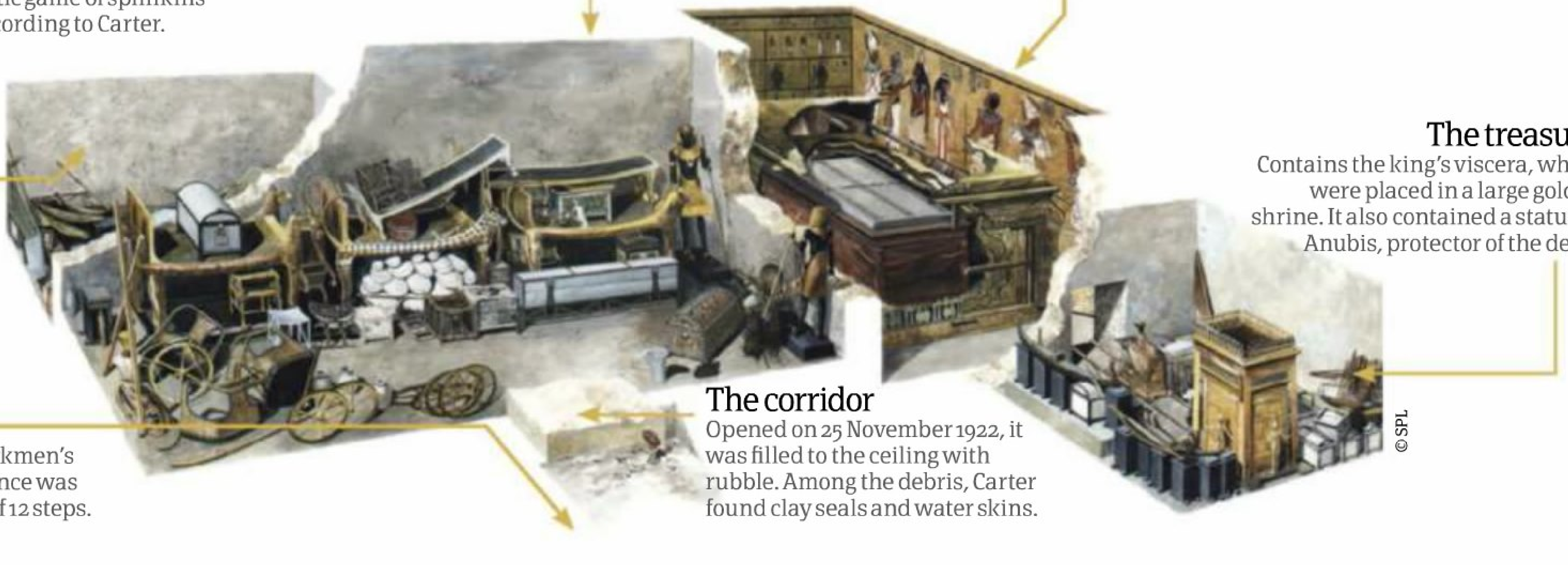
Who was Tutankhamun?

Tutankhamun began his life as Tutankhaten; the name highlights his role as the 'living image of the sun disc'.

Tutankhamun was the last ruler of a magnificent dynasty. His father is most likely to have been Akhenaten, Egypt's 'heretic' pharaoh. Akhenaten had shocked the world with his worship of a single solar deity – the Aten. On his accession, Tutankhamun faced a great period of transition as he re-established the old gods. Being young, his rule was dominated by a controversial figure – his uncle, the military commander, Ay.

Tutankhamun died between the ages of 18 and 20 when the throne passed to Ay. Some believe that the young king was assassinated.

Tomb of Gold



The antechamber
Contained a mass of 700 objects. Clearing it was like 'playing a gigantic game of spillikins [pick-up straws]', according to Carter.

The burial chamber
Contains the burial equipment of Tutankhamun. Here, Carter found the sarcophagus, coffins and human remains.

The annexe
The last room to be sealed in antiquity, the annexe was designed to hold oils, perfumes, food and wine.

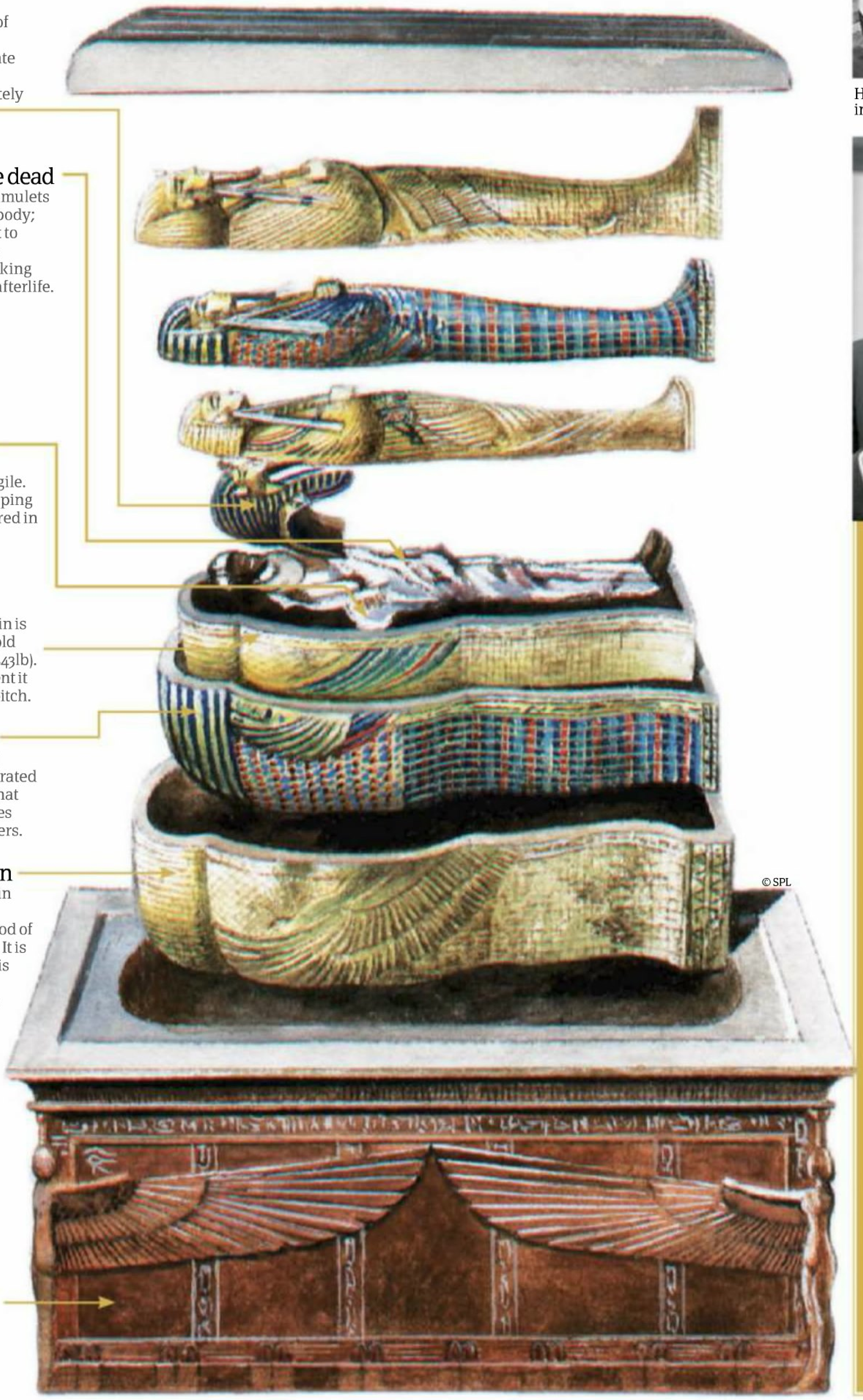
The treasury
Contains the king's viscera, which were placed in a large golden shrine. It also contained a statue of Anubis, protector of the dead.

The entrance
Once covered by workmen's huts, the tomb entrance was reached by a series of 12 steps.

The corridor
Opened on 25 November 1922, it was filled to the ceiling with rubble. Among the debris, Carter found clay seals and water skins.

© SPL

Within the sarcophagus



Gold mask
Shows the king as Osiris, the symbol of regeneration. It is made of two separate sheets of gold and weighs approximately 10kg (22lb).

Decorating the dead
A great number of amulets were found on the body; these were thought to embody protective properties that the king would need in the afterlife.

The mummy
Tutankhamun's mummy is very fragile. During the unwrapping process it was severed in several places.

Third coffin
The innermost coffin is made from sheet gold and weighs 110kg (243lb). During the interment it was covered with pitch.

Second coffin
Wrapped in a linen shroud, it was decorated by floral garlands that included olive leaves and blue lotus flowers.

The outer coffin
An anthropoid coffin that shows Tutankhamun as god of the afterlife, Osiris. It is made of wood that is overlaid with gold and measures in at over 2m (7ft) long.

The sarcophagus
The sarcophagus (meaning 'flesh eater') is carved at each corner with protective goddesses who spread their wings around the dead.

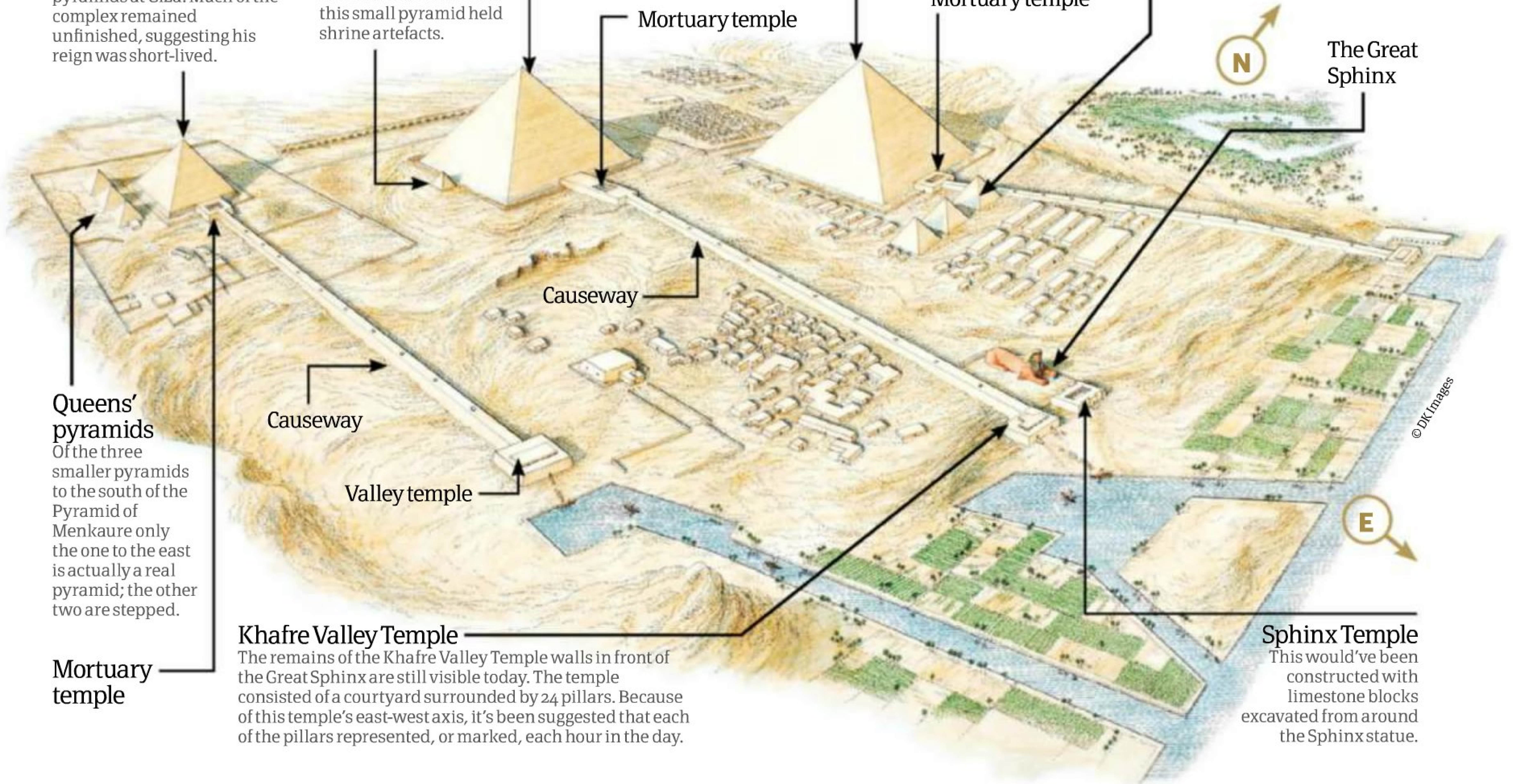
© SPL

Howard Carter takes a closer look inside the coffin

Who was Howard Carter?

Howard Carter was originally sent to Egypt as an artist. His elegant reproductions of ancient tomb paintings were well received. Carter fell in love with Egypt and began to take a more active role in excavating, making many important discoveries. Carter was sensitive and temperamental; his meticulous working practices and impatience with the politics of Egyptology led to his reputation as a maverick. Egyptian archaeology was dominated by the upper classes who thought Carter 'unpolished'. Carter, funded by Lord Carnarvon, an Egyptology enthusiast, began to dig in the Valley of the Kings. It was here, after several years of searching, that he found the tomb of Tutankhamun. Carter was never formally recognised for his achievements.

Layout of the Giza pyramid complex



Pyramid of Menkaure
Khafre's son, Mykerinos, built the smallest of the three pyramids at Giza. Much of the complex remained unfinished, suggesting his reign was short-lived.

Satellite pyramid
Only the outlines of the foundations remain but this small pyramid held shrine artefacts.

Pyramid of Khafre
Khufu's son, Khafre, built the second tallest pyramid at Giza, although it may appear tallest due to its location on a higher section of the Giza plateau.

Great Pyramid of Giza
The largest of the pyramids is the Great Pyramid (or Pyramid of Khufu), a royal tomb that would have taken something like 20 years to construct.

Queens' pyramids
Though these monuments were built for unknown queens, it's likely one was the burial place of Khufu's mother, Hetepheres I, as a cache containing items belonging to her was discovered near the northern-most pyramid.

The Great Sphinx

Queens' pyramids
Of the three smaller pyramids to the south of the Pyramid of Menkaure only the one to the east is actually a real pyramid; the other two are stepped.

Khafre Valley Temple
The remains of the Khafre Valley Temple walls in front of the Great Sphinx are still visible today. The temple consisted of a courtyard surrounded by 24 pillars. Because of this temple's east-west axis, it's been suggested that each of the pillars represented, or marked, each hour in the day.

Sphinx Temple
This would've been constructed with limestone blocks excavated from around the Sphinx statue.

© DK Images

How was the Great Sphinx built?

Discover the answers behind the mysteries surrounding the world's largest single-stone statue, and see how it was constructed

The Great Sphinx is the huge monolithic statue of a human-headed lion that was carved into a single mass of limestone bedrock on the western bank of the Nile during the third millennium BCE. The Sphinx itself faces directly east and its stonework features once included a cobra-embellished headdress and a beard.

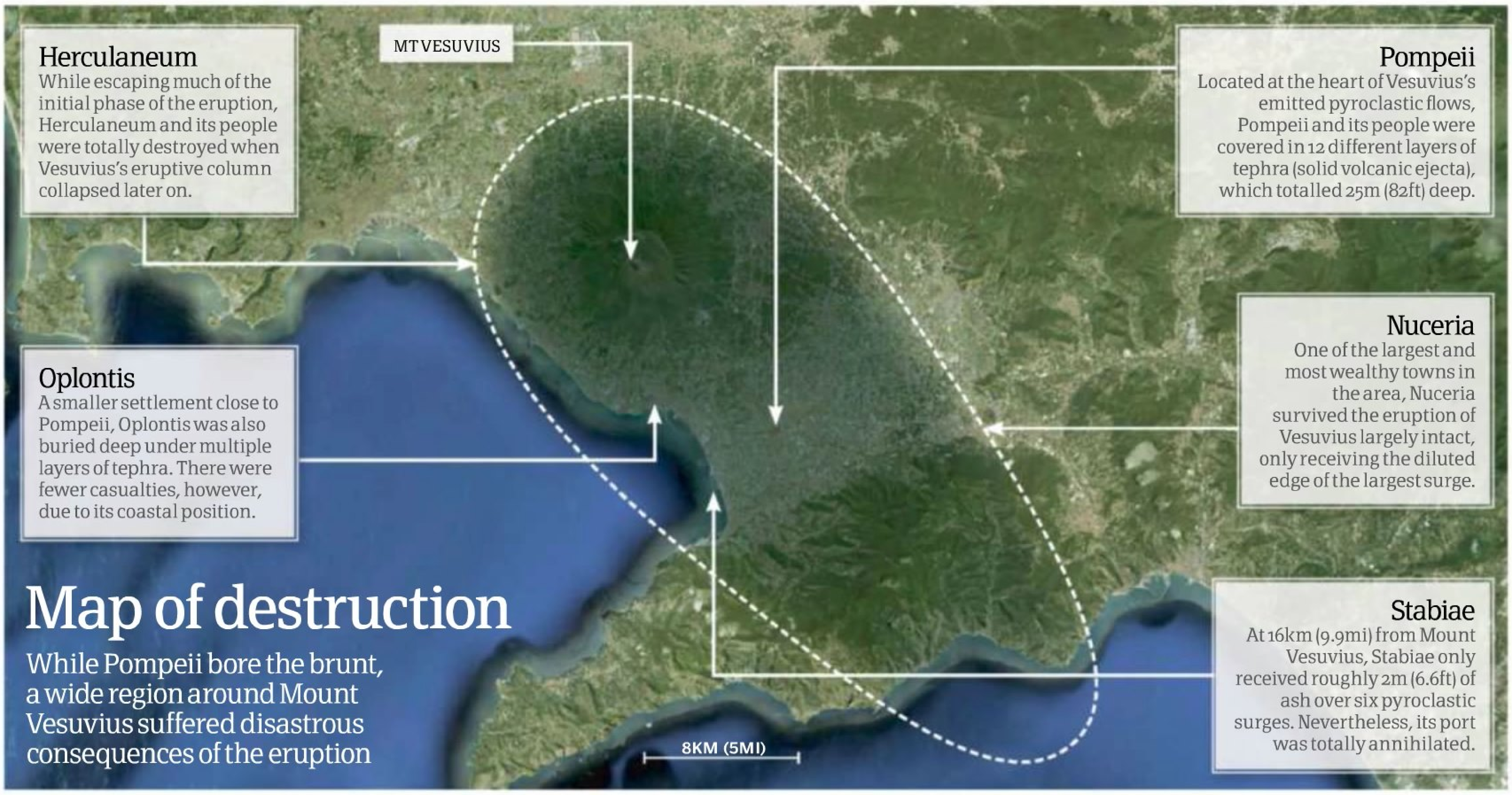
Though neither the Sphinx nor its principal architect were cited within the content of any hieroglyphs from the relevant time, the 'foreman' of the project is widely regarded to be Pharaoh Khafre (c. 2558-2532 BCE), the ruler of the Old Kingdom, which was a period of early Egyptian civilisation that endured for roughly 2,500 years. Incidentally, Khafre's father – Khufu (c. 2589-2566 BCE) – built the Great Pyramid at Giza approximately 400 metres (1,300 feet) from where the Sphinx statue would later be carved.

Regarding the identity of the labour force who performed all the heavy lifting, an Old Kingdom cemetery containing the tombs of some 600 possible workers and overseers was unearthed back in the early-Nineties. Following that, in 1999 Egyptian archaeologist Mark Lehner found a settlement dating back to the reign of Khafre, capable of accommodating between 1,600 and 2,000 people – a rather convenient Sphinx construction workforce, perhaps?

4,500 years ago, before bronze and iron were prevalent, the available tools for this colossal undertaking would have included copper implements and stone hammers. Modern reconstructions, using similar stone and ancient-style tools, have estimated that the Great Sphinx could have been constructed in just three years with 100 people chipping away at a rate of 0.03 cubic metres (one cubic foot) per week.

Using the huge excavation of stone quarried away from the Sphinx enclosure (the pit in which the statue sits), the labourers were also able to construct the nearby Sphinx Temple. Each block that was removed from the Sphinx statue site could have weighed up to 200 tons and would have been transported on rollers.

Until the Thirties, when an archaeologist called Selim Hassan excavated the lower half of the statue, the Great Sphinx remained buried up to its shoulders by sand. Today it stands proud alongside the other monuments of Giza as a testament to the engineering skill of the Ancient Egyptian civilisation.



Herculaneum
While escaping much of the initial phase of the eruption, Herculaneum and its people were totally destroyed when Vesuvius's eruptive column collapsed later on.

Oplontis
A smaller settlement close to Pompeii, Oplontis was also buried deep under multiple layers of tephra. There were fewer casualties, however, due to its coastal position.

Pompeii
Located at the heart of Vesuvius's emitted pyroclastic flows, Pompeii and its people were covered in 12 different layers of tephra (solid volcanic ejecta), which totalled 25m (82ft) deep.

Nuceria
One of the largest and most wealthy towns in the area, Nuceria survived the eruption of Vesuvius largely intact, only receiving the diluted edge of the largest surge.

Stabiae
At 16km (9.9mi) from Mount Vesuvius, Stabiae only received roughly 2m (6.6ft) of ash over six pyroclastic surges. Nevertheless, its port was totally annihilated.

Map of destruction

While Pompeii bore the brunt, a wide region around Mount Vesuvius suffered disastrous consequences of the eruption

© Google

What caused the destruction of Pompeii?

When Mount Vesuvius erupted in 79 CE, it wiped the city of Pompeii off the face of the planet, burying both it and its citizens under tons of volcanic fallout

Pompeii was a medium-sized Roman city in the Italian region of Campania. In 79 CE, however, it was completely destroyed in the eruption of nearby Mount Vesuvius, a stratovolcano located close to the city of Naples.

The destruction of Pompeii (and other cities; see 'Map of destruction') was caused according to stratigraphic studies in two main phases. The first phase was a Plinian eruption, which is typified by a colossal ejection of gas and volcanic ash high into the stratosphere. This phase lasted roughly 20 hours and produced a rain of pumice in a southwards-reaching cone that stretched for over 32 kilometres (20 miles).

The second – and for the people of Pompeii, even more deadly – phase was a Peléan eruption, which consisted of a number of vast pyroclastic flows. These flows were fast-moving currents of superheated gas (at roughly 1,000 degrees Celsius/1,800 degrees Fahrenheit) and rock that rapidly dispersed at ground level into the surrounding area. The combination of both these phases led to the burning and asphyxiation of all life that stood in harm's way.

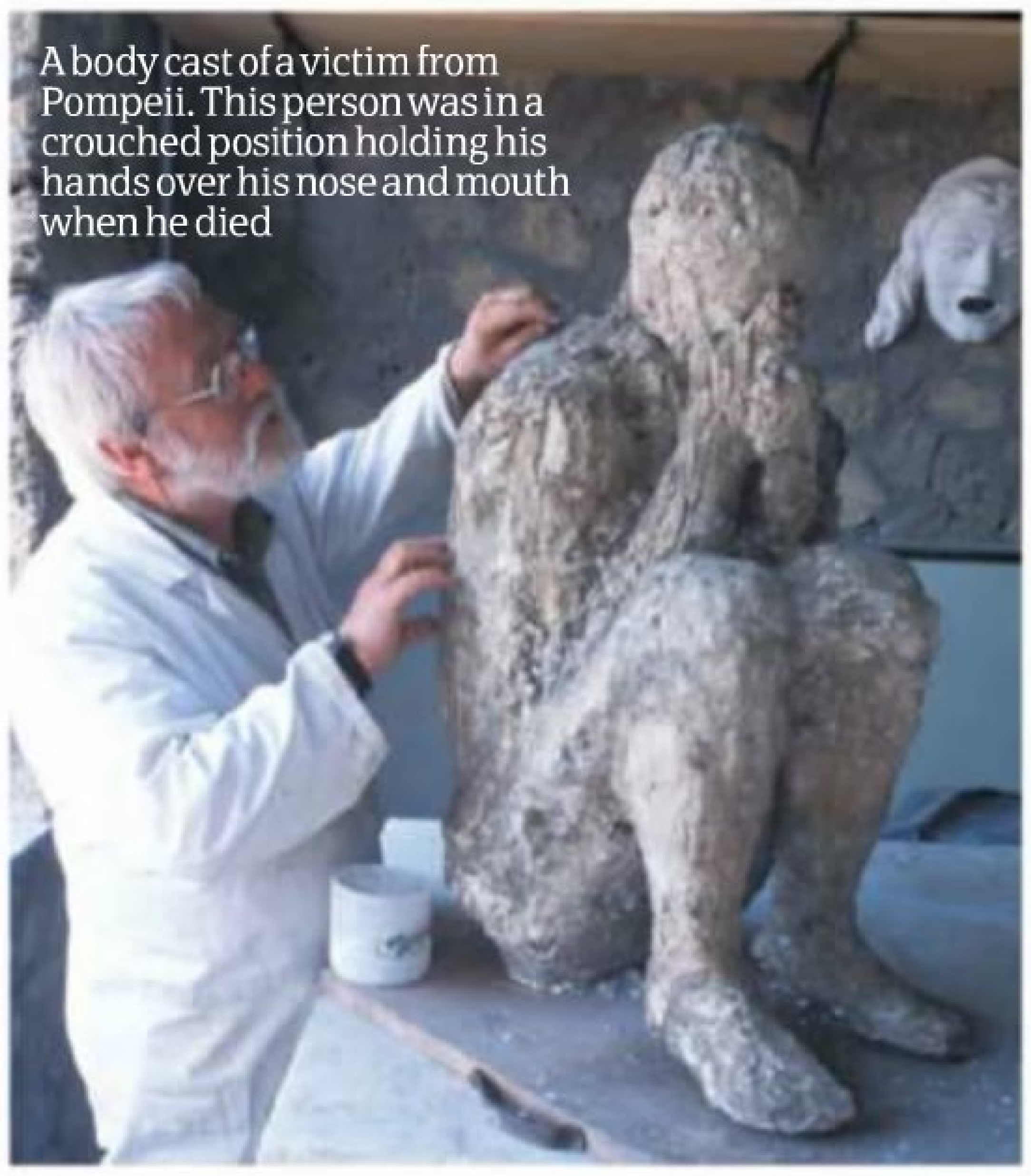
In addition, the eruption caused a small tsunami in the nearby Bay of Naples, rendering escape attempts by boat impossible, and a series of tremors that aided the destruction of dwellings and temples.

Today, over a thousand casts have been made from impressions of bodies trapped in Vesuvius's ash and flow deposits discovered in and around Pompeii, along with various other scattered remains. Out of the total found, 38 per cent were discovered in ash fall, with the remaining 62 per cent found in surge deposits. Unfortunately, due to a lack of official documentation from the time, what percentage these represent of Pompeii's total population is unknown.

Since the eruption of 79 CE, Vesuvius has erupted more than 30 times, the last occurring in March 1944. Despite this, the area surrounding Mount Vesuvius continues to be lived in by many Italians, with the entire region in its immediate vicinity colonised. To combat the potential for disaster, the Italian government foresees the need for an emergency evacuation of over 600,000 people and has marked a 'Red Zone' for those areas that would be most affected.

Mount Vesuvius as seen today from above

© Pastorius


A body cast of a victim from Pompeii. This person was in a crouched position holding his hands over his nose and mouth when he died

© Jjkael

How was Venice built?

How was the much-loved Italian city constructed on top of marshland, and what stops it from flooding?

Despite Venice being frequently voted the world's most beautiful city, on paper it appears to be a logistical and constructional nightmare. It is built, largely, on marshland – a lagoon which is just eight per cent land, and one that contains some of the largest and heaviest religious and administrative buildings in Italy. And that's not even accounting for the dwellings of an estimated 60,000 residents and the risk (a very real risk as shown by history) of cataclysmic flooding. This, of course, raises the question: how does Venice keep above the water?

Key to its construction is an ancient method of using raised foundations, which effectively elevate ground zero to a height where buildings can be safeguarded from tidal waters. This involves the hammering of thousands of pilings – large wooden stakes commonly made from alder – through the water and into the underlying sand and clay. Each piling is positioned very closely to its neighbouring stake, one after the other, ultimately forming a raised wooden platform. Once a certain number of pilings has been driven into the earth, the tops are evened off and a substrate (or foundation layer) of wood and marble laid over the top. It is upon this which Venice's buildings are constructed.

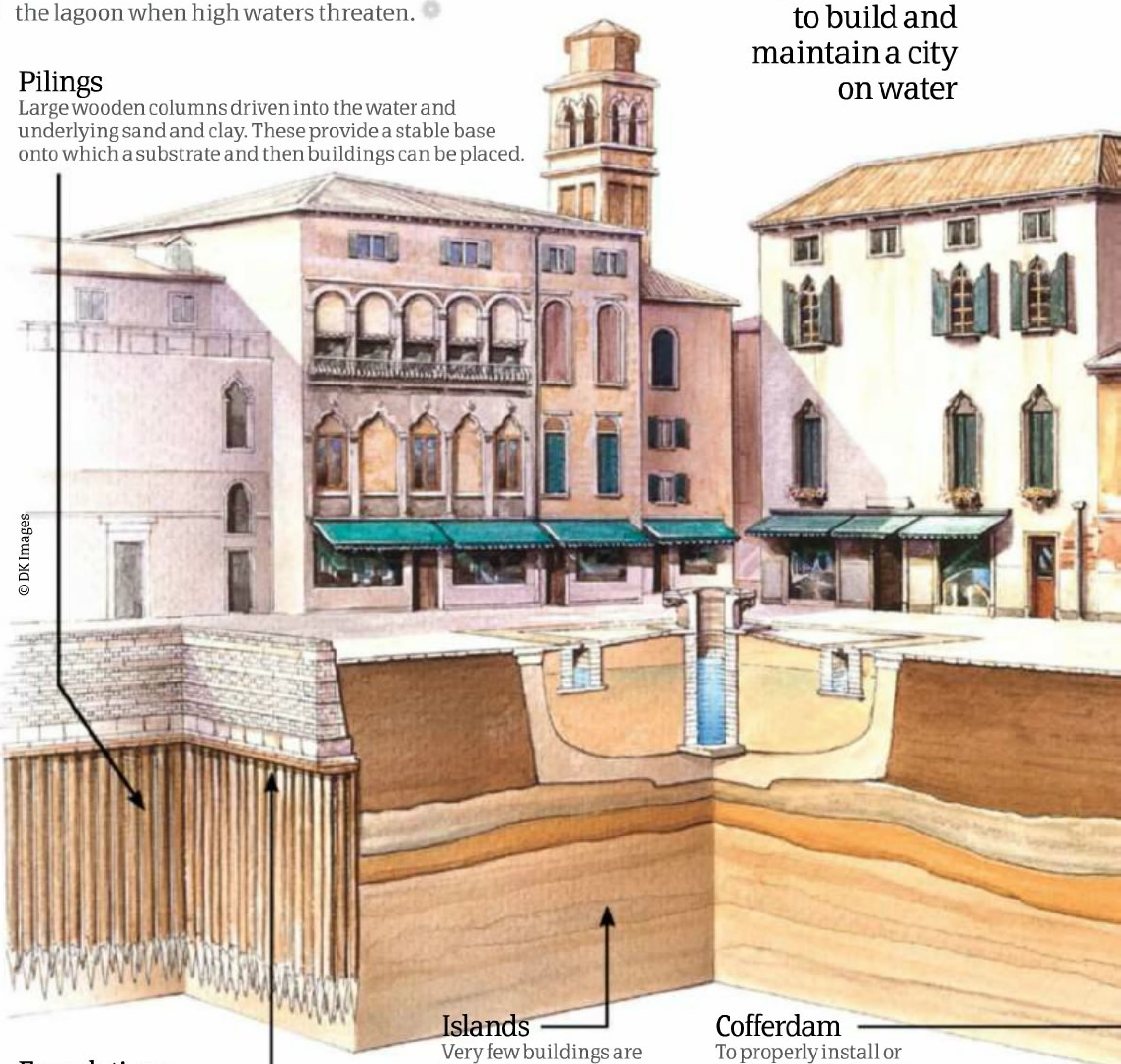
Of course, raising buildings out of the water is but one half of building in Venice – the other being to successfully channel the lagoon's waters into commutable highways. Venice's canals, which run for a total of 42 kilometres (26 miles), are built and maintained in a multi-stage – and never-ending – process that begins with the construction of a cofferdam. A cofferdam is a temporary barricade that, once erected, allows a portion of the lagoon's waters to be blocked and redirected, which is necessary for any building work to take place. Once the damming structure is in place, the draining of the area can start, with industrial pumps removing any remaining water held in the channel. Next, large-scale dredging takes place, with huge diggers and cranes excavating the channel.

Once the channel is clear, engineers can begin fortification of the canal, utilising pilings, bricks, clay and – more frequently in recent years – cement to line and strengthen its core structure. Wooden pilings are still used today because, when submerged, the almost zero-oxygen environment of the canal preserves them incredibly well, as well as bolstering their strength further through petrification – an effect caused by the flow of mineral-rich waters in their immediate vicinity.

Finally, and most topically, Venice's construction is protected by a series of flood-prevention mechanisms. These range from the installation of conventional concrete dams around the city, through to a project initiated in 2003 (MOSE) to set up huge inflatable pontoons at the mouth of the lagoon when high waters threaten.

The floating city explained

Breaking down the materials, tools and techniques required to build and maintain a city on water



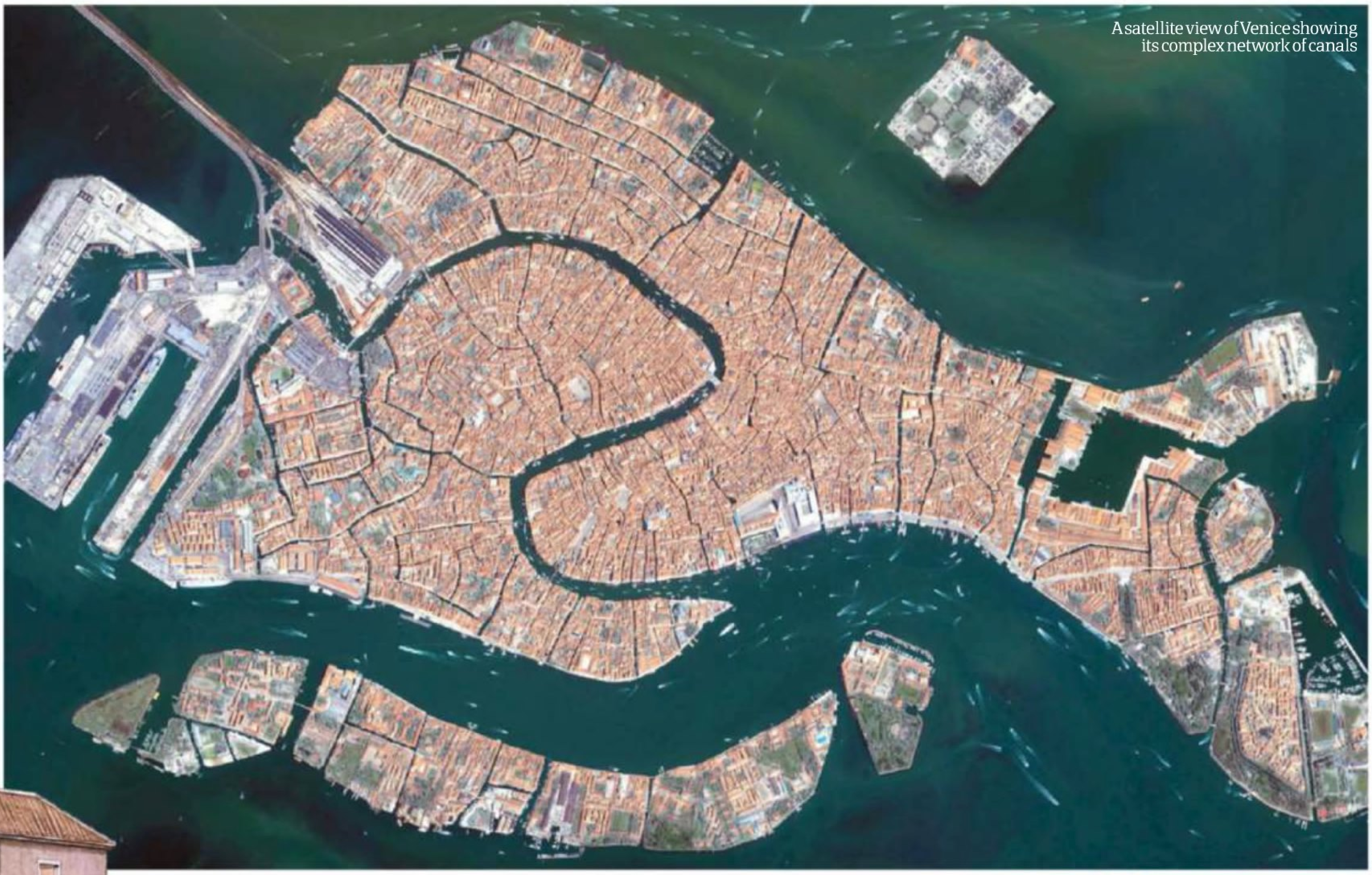
© DK Images

Pilings
Large wooden columns driven into the water and underlying sand and clay. These provide a stable base onto which a substrate and then buildings can be placed.

Foundations
Venice's buildings are not placed directly onto pilings but rather a dual-layer substrate made from, firstly, planks of wood and, secondly, thick sheets of marble – the latter being water resistant.

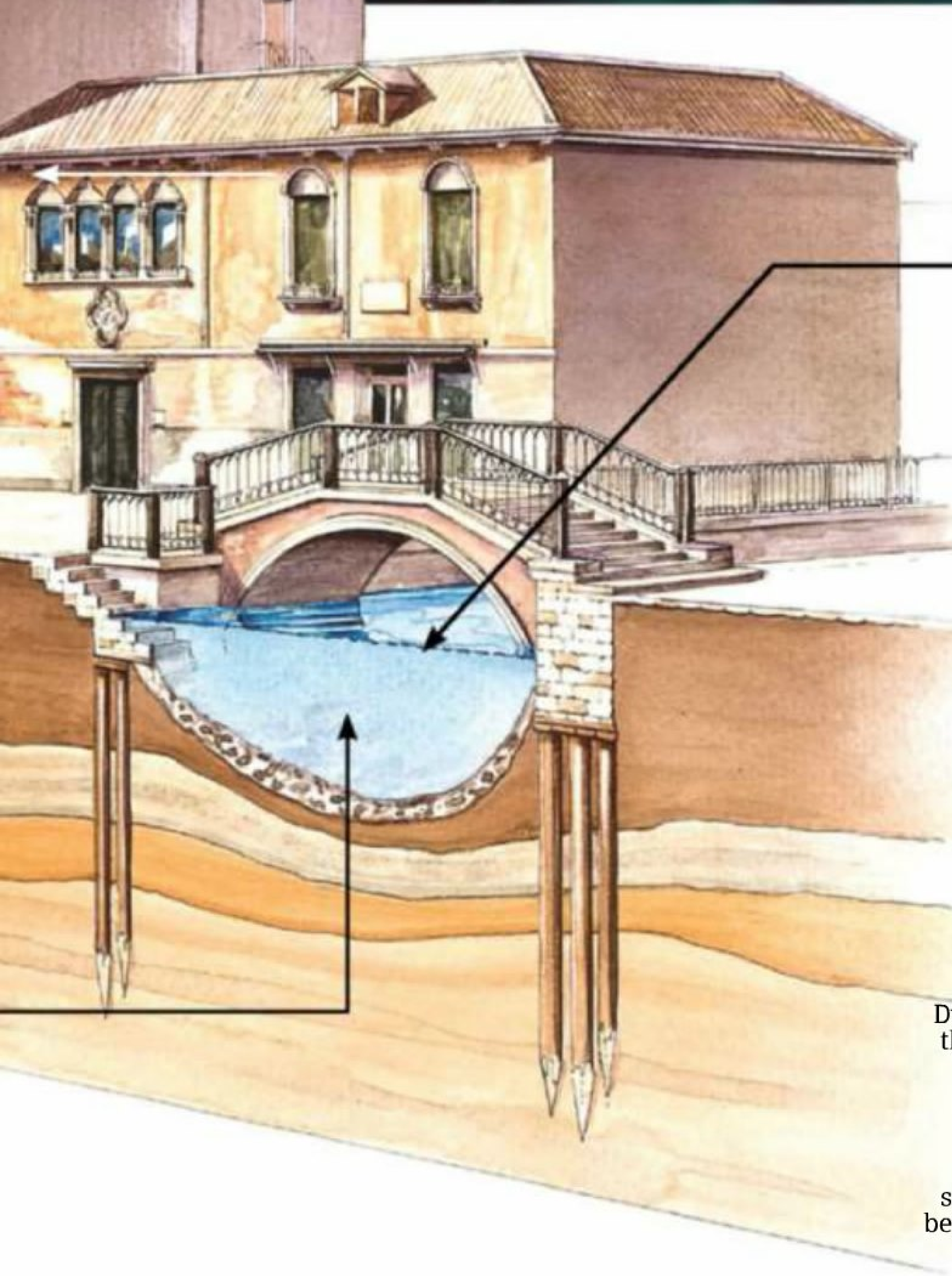
Islands
Very few buildings are built solely on pilings alone, with the Venetian Lagoon containing 117 small islands atop, or off of, which the majority of structures are assembled.

Cofferdam
To properly install or maintain existing pilings, as well as the canal walls themselves, engineers erect temporary dams called cofferdams in order to cut off/divert water flow.



A satellite view of Venice showing its complex network of canals

© ESA



Dredging

Dredging is an ongoing activity in Venice due to the buildup of debris in and around its canals. Floating diggers are used to haul the flotsam and jetsam into mobile skips.

A floating excavator dredges debris from one of Venice's canals

© Nino Barbieri

Due to the continual threat of flooding, a detailed model of the city has been created through which scientists can test certain scenarios to ensure better flood defences

© SPL

What made star forts unique?

Why are these spectacular fortifications shaped this way?

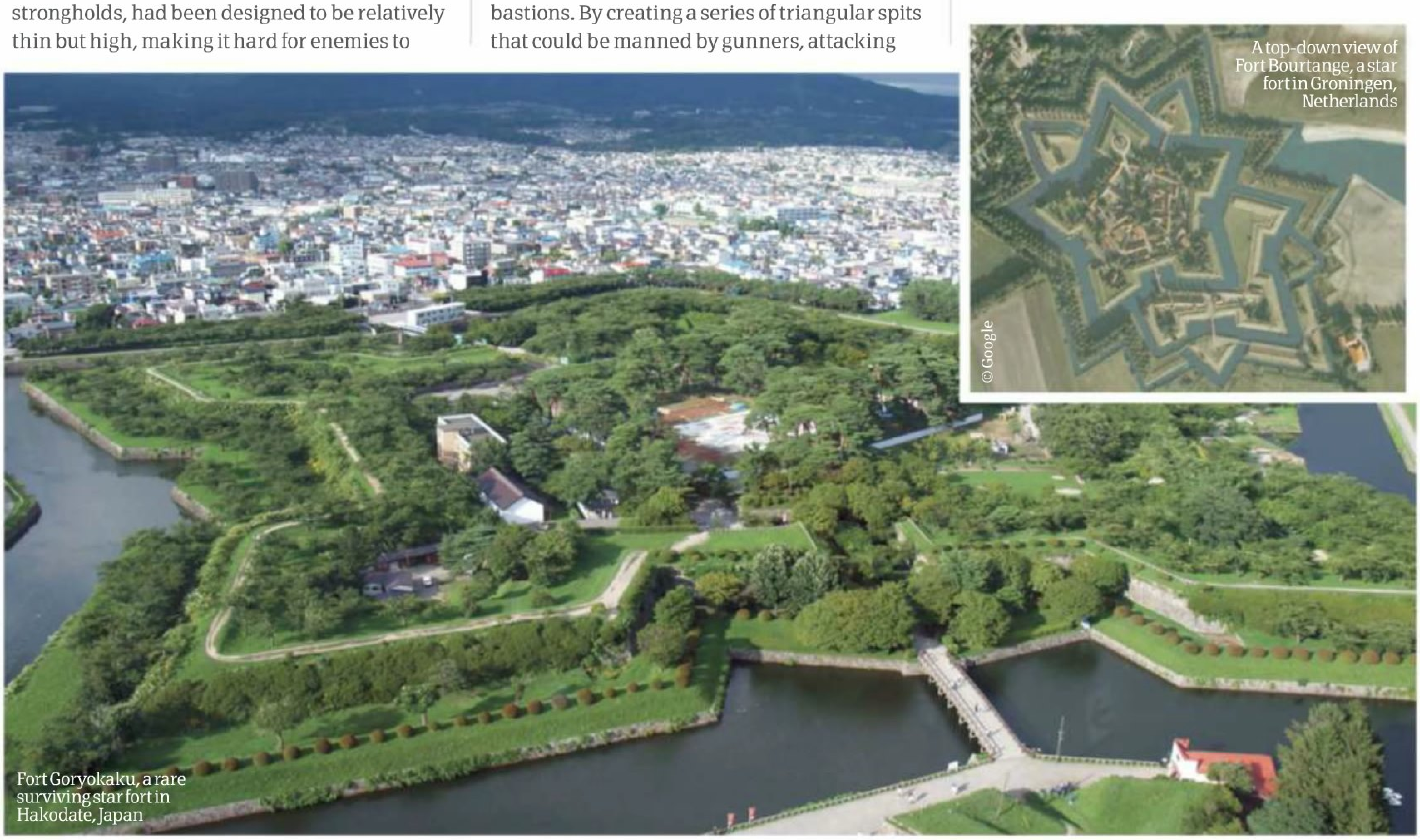
Star forts are a type of fortification that remained popular from the mid-15th Century right up until the end of the 19th and they evolved for two main reasons. First, they aimed to counteract the game-changing effects of gunpowder during sieges, with traditional square and ring-shaped forts now easily breached by cannon fire. Second, star forts also mitigated a key defensive weakness traditional forts had become increasingly vulnerable to – 'sapping', or mining under the walls, by foes out of the firing line .

Star forts countered – to a degree – the effects of cannon fire by removing most perpendicular targets for the attacking force. The design was chosen as cannon balls made short work of square-on fortifications largely due to their extensive surface area and lack of absorptive support when a shot made contact. This was because medieval castle and fort walls, which accounted for a large proportion of existing strongholds, had been designed to be relatively thin but high, making it hard for enemies to scale them and difficult for siege engines to fire over. The advent of cannon fire, however, allowed these walls to be hit directly and with a ferocity that would easily demolish the stone and clay.

As such, this new form of fortification was built out of a series of interlocking and/or separate triangular bastions, which encircled the central town or keep within. The bastions were much thicker than standard walls and much flatter too, meaning that any cannon shot hitting them straight on would have its kinetic energy spread out and absorbed by successive layers of masonry. Further, any shot that was not a direct hit, or completely perpendicular, would glance off with little damaging effect.

The second reason why the star-shaped fort became widely adopted was that while it limited effective angles of attack for the offensive enemy force, it maximised those of the defensive one. This was due, simply, to the geometry of their bastions. By creating a series of triangular spits that could be manned by gunners, attacking forces could be engaged over a far greater angle – over 180 degrees – and, more importantly, those forces that did reach the walls, could be continuously fired on from the side and rear. These advantages were generally not granted by existing strongholds, as their flat-on walls meant infantry could only fire in a small arc in one direction – ie perpendicular to the wall. If forces did manage to reach the base, they could not be effectively engaged either as shooting straight down is very awkward.

Despite originating in the mid-15th Century in Italy, by the start of the 18th Century star forts were a common sight in France, Germany, Croatia, Hungary and many other western nations (later spreading as far east as Japan). Many are acclaimed in historical record as key turning points in major battles. Indeed, the reign of the star fort only came to an end with the arrival of explosive shells towards the latter end of the 19th Century.


A top-down view of Fort Bourtange, a star fort in Groningen, Netherlands

© Google

Fort Goryokaku, a rare surviving star fort in Hakodate, Japan

How were Roman roads built?

How were these ancient highways made, and were they always straight?

While the concept of roads had existed for hundreds of years prior to the Romans, it was through the Roman Republic's – and later Roman Empire's – widespread use of them throughout Italy and beyond that most of ancient Europe became so well connected. In addition, they contributed heavily to the spread of the territories under Roman control as they enabled troops, supplies and traders to quickly travel from place to place.

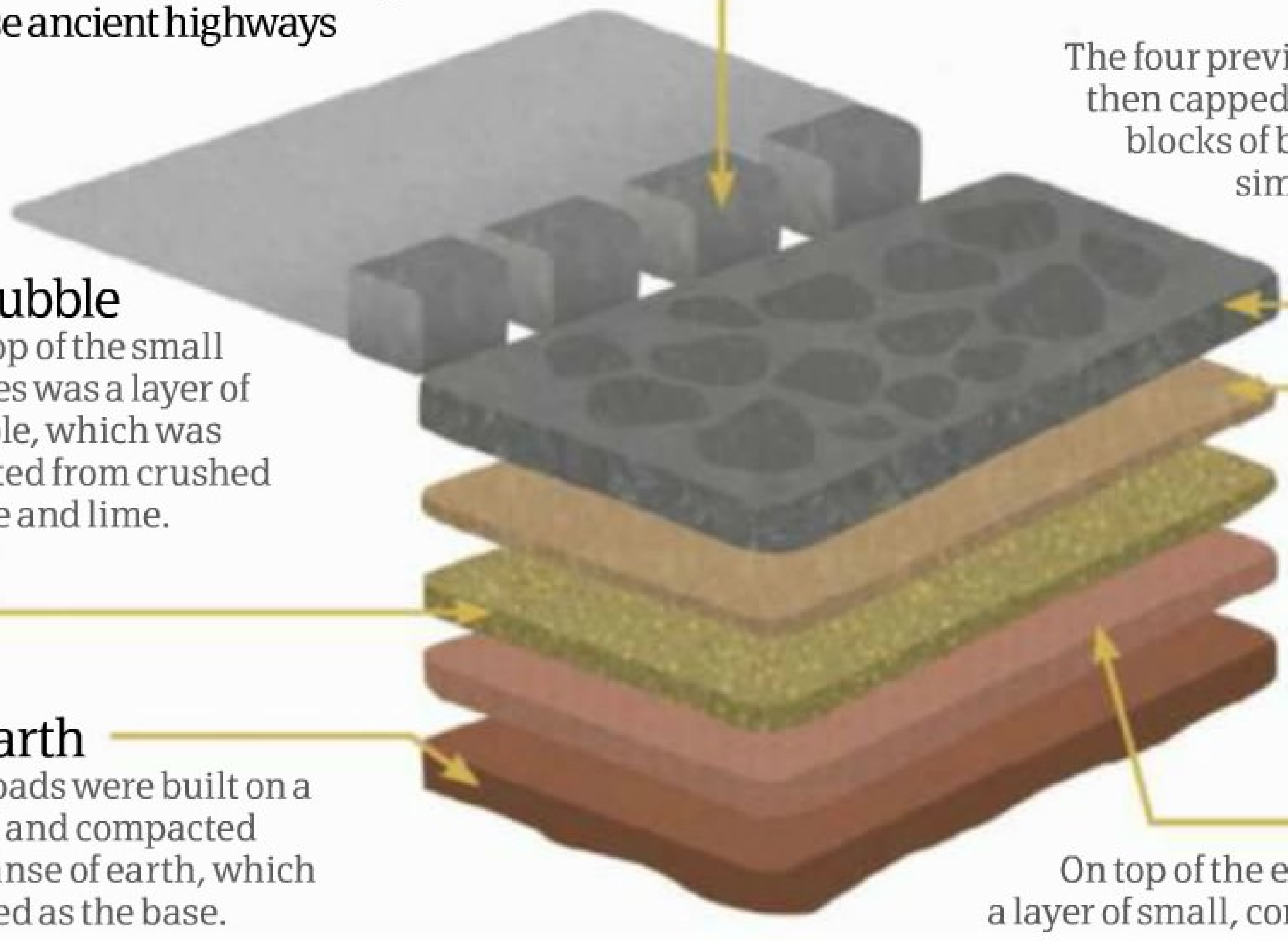
Roman road construction was heavily institutionalised, with set materials and designs. Roads were of a certain width and depth, consisting of a number of layers built up from a pre-dug trench. The roads were also split up into a number of categories, depending on their size, ownership and purpose. For example, viae publicae were large main roads, maintained through public taxation, while viae privatae were funded and built by private individuals.

While Roman construction rules did indicate roads should be built straight wherever it was possible, this was not in practice typical, with only major high roads built that way. Indeed, many private and country roads took variable routes to their destinations and, due to their maintenance being handled by a provincial authority, were often altered over time to better suit the locals.

A Roman road in Jerash, Jordan

Anatomy of a Roman road

Unveiling the multiple layers that went into constructing these ancient highways



6. Edge
On either side of the capping layer – ie the road's surface – raised edge stones were positioned to demarcate the pavements.

5. Lava
The four previous layers were then capped with polygonal blocks of basaltic lava or a similar hard stone.

3. Rubble
On top of the small stones was a layer of rubble, which was created from crushed stone and lime.

4. Lime
A bedding of pounded pot shards and lime was then deposited over the rubble and compressed.

1. Earth
All roads were built on a level and compacted expanse of earth, which served as the base.

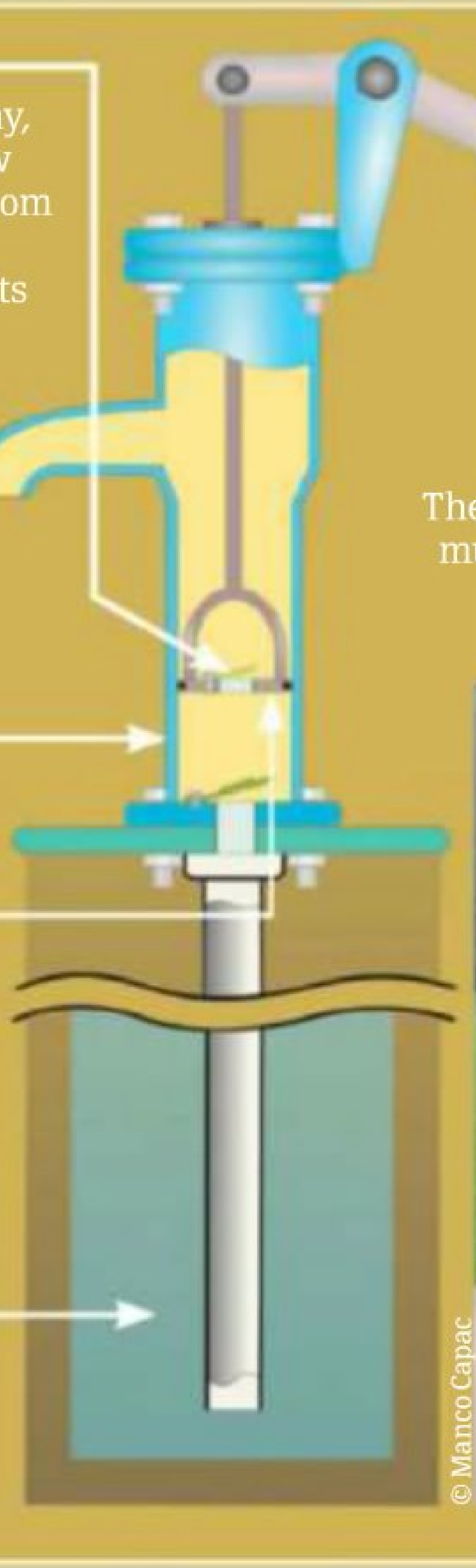
2. Stones
On top of the earth was placed a layer of small, compacted stones.

How do water pumps work?

We break down a manual water pump to see how it delivers H_2O

There are many different types of water pump, however the most common are positive displacement varieties, such as the manually operated piston pumps which are often found in parks, as well as developing countries.

Positive displacement pumps work by trapping water from a central reservoir and then forcing its volume upwards into a discharge pipe. This is achieved most commonly through the use of a valved piston and cylinder, which when combined, draw water via suction up into a cylinder, before redistributing it through a descending valved piston head into an expanding higher chamber. When the piston begins to rise, its own valve is forced shut by increased pressure within the higher cylinder chamber, while the cylinder's reservoir valve is pulled open by a release of pressure in the lower chamber. This allows pockets of water to be continuously drawn up from an underground source to an outlet on the surface.



Check valves
The check valves are one-way, non-return valves, and allow water to pass through first from the reservoir and second through the piston head on its journey to the surface.

Cylinder
The vertical body of the pump, the cylinder provides an enclosed compartment for the pump's piston to move through.

Piston
The piston descends and ascends through the cylinder, with water from the lower chamber forced through its head valve via an increase in pressure.

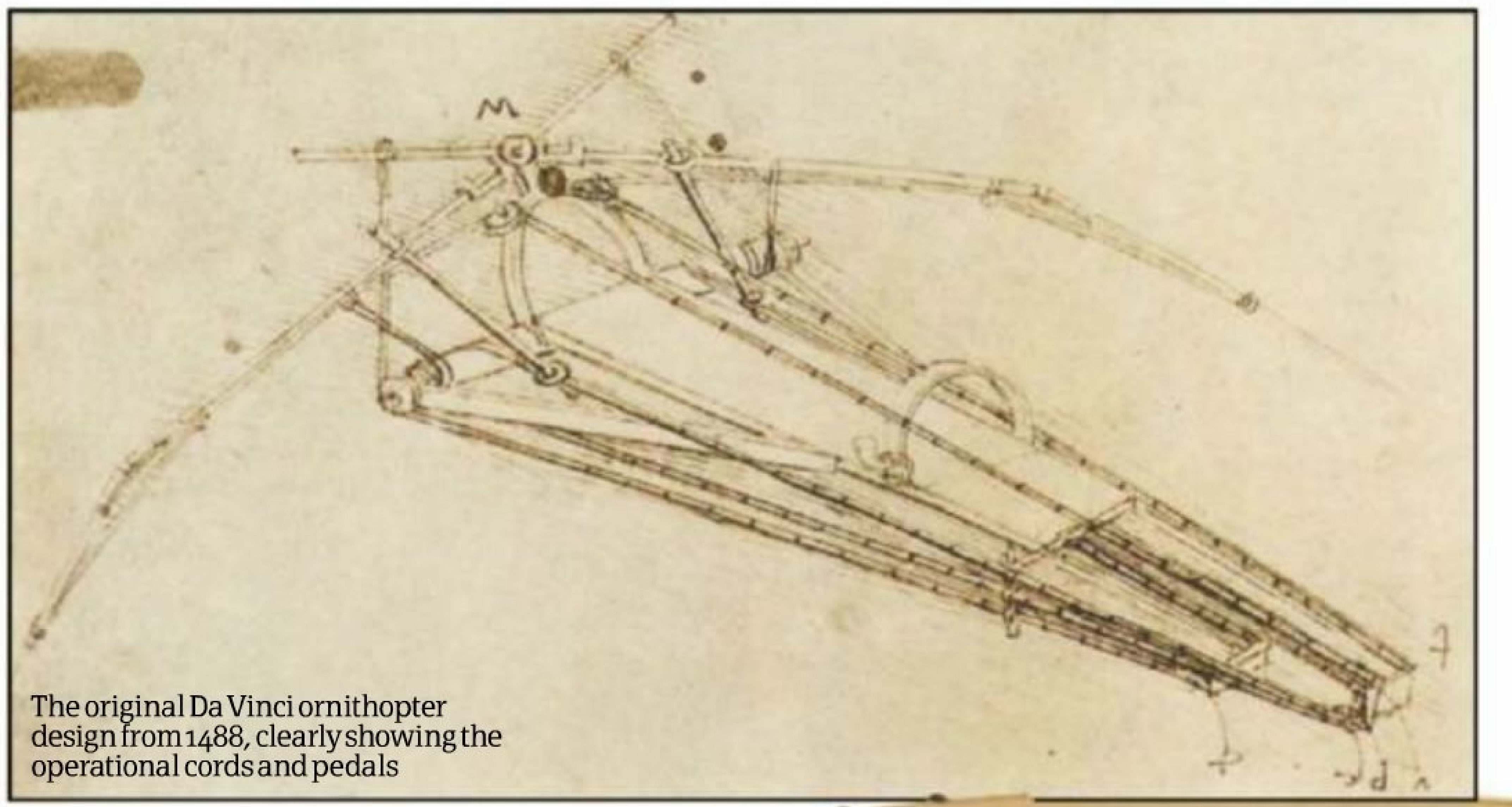
Reservoir
A mediating tank or chamber where the pump's water is stored ready for extraction.

Force rod
The external lever of the pump, the user must apply force to this rod to draw the piston up and down the cylinder.

© Manco Capac

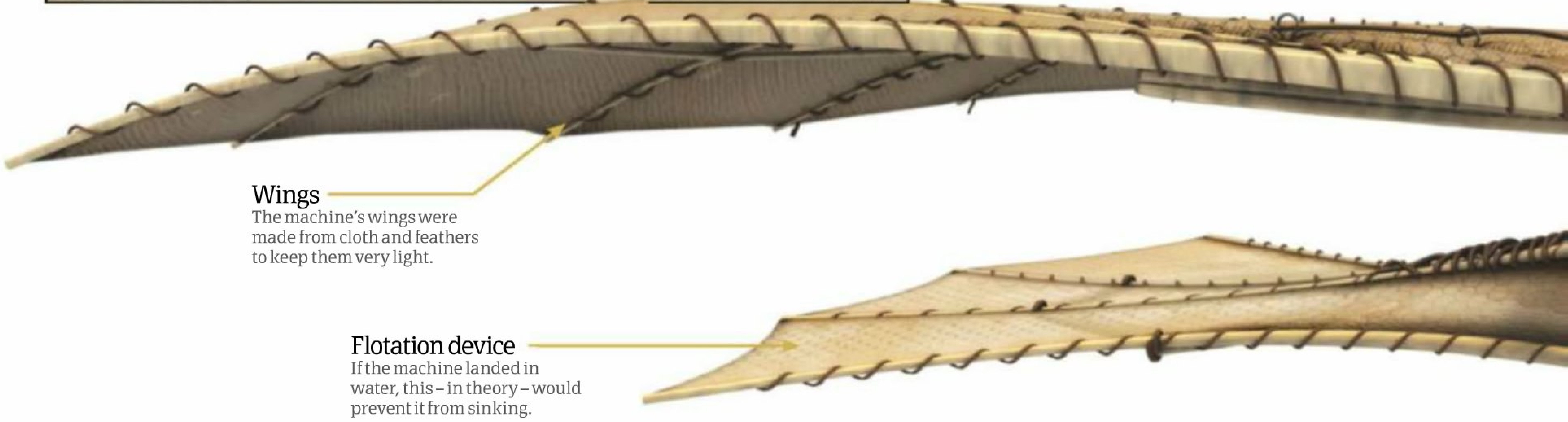
A piston hand pump at the Hinckley Reservation, Ohio

© Analogue Kid



The original Da Vinci ornithopter design from 1488, clearly showing the operational cords and pedals

> “Surprisingly, Da Vinci never built the machine for himself in the 15th Century, nor did he test it”



Wings
The machine's wings were made from cloth and feathers to keep them very light.

Flotation device
If the machine landed in water, this – in theory – would prevent it from sinking.

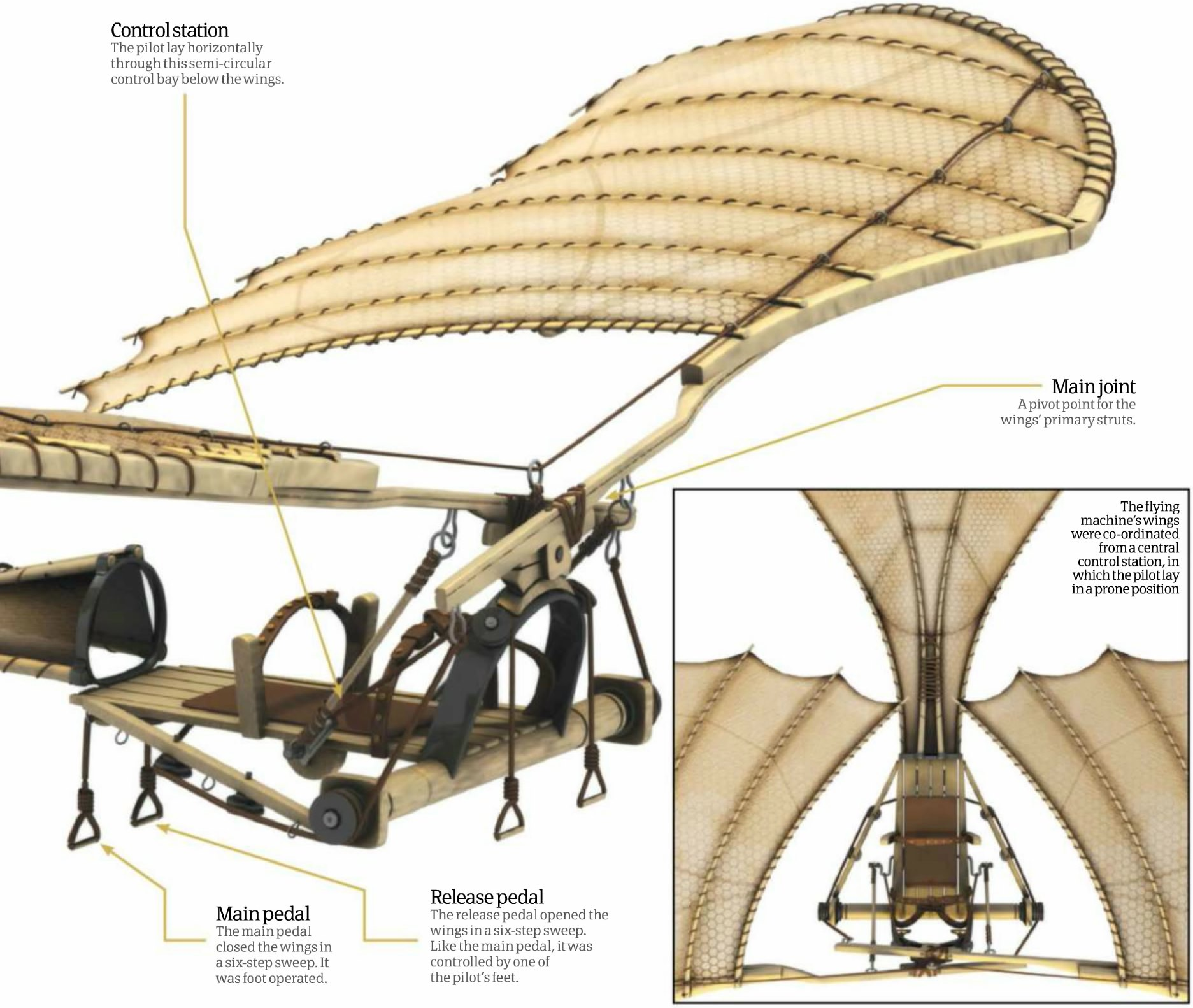
What was Da Vinci's flying machine?

Discover the operation of one of Da Vinci's most famous aviation designs, the ornithopter

This image is a 3D interpretation of Leonardo Da Vinci's flying machine, the ornithopter. Da Vinci designed the contraption in 1488 after studying the flight mechanics of birds. Indeed, in many regards the flying apparatus shares a lot of common features to the expert fliers, including a flexing, compound flapping motion as well as lightweight, feathered wings.

The flying machine operates as follows. A pilot lies down on top of the central wooden plank, hooking their neck and head through the semi-circle hoop and legs through the rear fastener. Once in position, the pilot can operate all parts of the machine with either their hands or feet. Foot operation entails pushing on two pedals situated at the rear of the aircraft – one opening the wings and the other closing them. The pilot's hands, meanwhile, can grip the frame and ensure smooth running of the cording, which is responsible for controlling the wings' multiple wooden struts.

Surprisingly, Da Vinci never built the machine for himself in the 15th Century, nor did he proceed to test it – maybe due to the financial challenge such a project would entail, or the large potential for injury. In addition, while many enthusiasts have created direct replicas of the ornithopter from the original schematics drawn out by Da Vinci himself, no one has actually attempted to fly them yet, despite the mechanisms having been confirmed as fully functional and possible of flight.



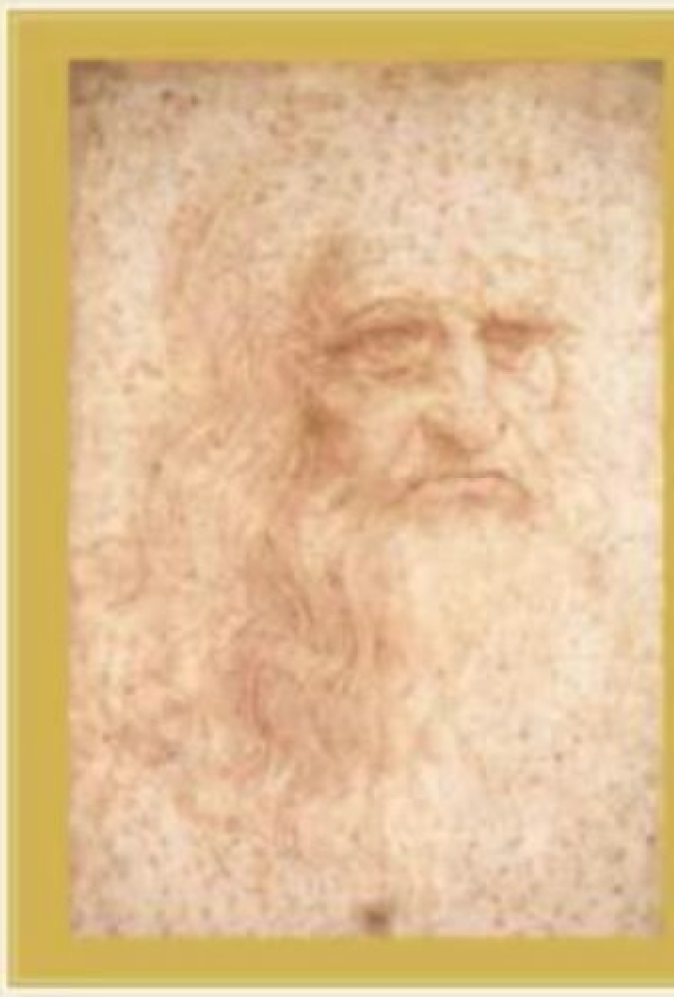
Control station
The pilot lay horizontally through this semi-circular control bay below the wings.

Main joint
A pivot point for the wings' primary struts.

Main pedal
The main pedal closed the wings in a six-step sweep. It was foot operated.

Release pedal
The release pedal opened the wings in a six-step sweep. Like the main pedal, it was controlled by one of the pilot's feet.

The flying machine's wings were co-ordinated from a central control station, in which the pilot lay in a prone position



Who was Da Vinci?

An irrepressible inventor, Da Vinci created many machines and gadgets still in use today

Leonardo Da Vinci was an Italian Renaissance polymath (a learned person of many talents). Most well known for his paintings – including *The Mona Lisa* – He successfully conceived and built a wide number of tools, mechanisms and machines, many of which are still used in some form to this day. Examples include the machine gun, armoured car, bicycle, mechanical saw, dredger, file-cutter, excavating crane, mechanical drum and odometer.

In addition, he drew out numerous fantastical designs for more ambitious inventions that unfortunately never got adopted, one of which was the flying machine that is examined in more detail here. Other examples include a mechanical dragonfly, a self-propelled cart and a skull-shaped lyre. Leonardo Da Vinci was born near Vinci, Italy, on 15 April 1452 and died near Amboise, France, on 2 May 1519, aged 67.

> “Only true blows generated points, with a true blow consisting of the lance shattering on impact”

How did jousting work?

High-speed, brutal and theatrical – it’s easy to see why this martial sport was so popular in the Middle Ages

Jousting was a martial sporting event undertaken between two horsemen using lances, each aiming to strike the other and unhorse him. It worked either as a single event or as part of a larger tournament, the latter involving other athletic disciplines such as hand-to-hand combat.

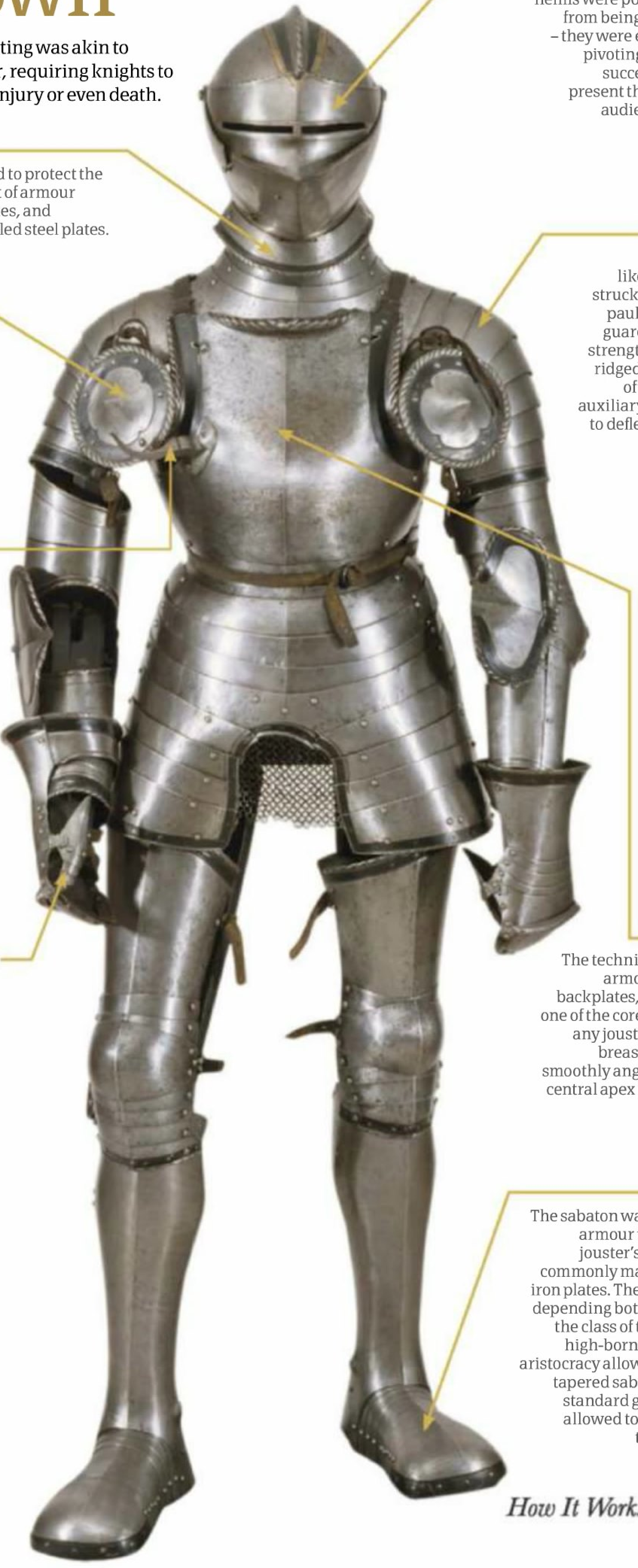
The joust itself, however, worked on a point-scoring system, with each true blow struck on the opponent generating a number of points for the striker, the total depending on where the blow landed. So, if a rider hit his opponent on the helmet he was awarded two points, while if he struck them on the breastplate only a single point would be awarded. If a rider unhorsed his opponent with a strike then he was awarded three points and the match was considered over. Importantly, however, only true blows generated points, with a true blow consisting of the lance shattering on impact. Glancing blows, low blows and any strike that did not shatter the lance were not counted.

For each joust both horsemen were equipped with a trio of lances, to be used over a series of three charges. All lances were measured before each joust to ensure they were of equal length and therefore no reach advantage could be sought by one of the horsemen. In addition, strict rules governed each meeting, with only the horseman’s squire (assistant) allowed to hand him new lances or help him in the event of an unhorsing. As part of these rules, it was also mandatory that any knight competing own the horse and armour he was using, as in the event that they were unhorsed, their opponent could demand both as a victory trophy. Of course, all these rules came behind the first and most important, which stated that only noblemen could compete.

If the joust was held as part of a larger competition, the other key event was the hand-to-hand combat match. This worked along a similar set of rules to the joust proper, with the first knight to land three blows on his opponent the victor. Which weapons and styles were

Jousting armour breakdown

Being hit with a lance while jousting was akin to being struck by a sledgehammer, requiring knights to bolster their steel plate to avoid injury or even death.



Gorget
The gorget was a steel collar designed to protect the knight's throat. It slotted into the suit of armour underneath the breast- and backplates, and typically comprised layered and angled steel plates.

Besagew
Due to reduced necessity of movement while charging in horseback jousts, knights would often equip besagews (small circular shields) to their armour. These were designed to provide extra protection at joints – such as the armpit – where gaps in the plate could be exploited.

Lancer
A unique adaptation to standard plate armour was a lance holder, which was positioned beneath the right-arm pauldron. The steel hook was welded to the breastplate and helped support the lance while charging, allowing for a greater strike accuracy.

Gauntlet
Jousting gauntlets were designed to maximise the combatant's grip of their lance and, as such, Almain rivet type designs were commonly used. These consisted of layered, overlapping steel plates augmented with reinforced knuckle and fingertip caps, which covered only the top and sides of the hands, leaving the underside free to grip through a leather/fabric glove.

Helmet
Due to bonus points being awarded for a head strike, jousting helmets were heavily modified to add more protection. Armets and close helms were popular, as – aside from being sharply angled – they were equipped with a pivoting visor, allowing successful knights to present themselves to the audience post-battle.

Pauldron
Due to the high likelihood of being struck in the shoulder, pauldrons (shoulder guards) were heavily strengthened. Thicker, ridged steel was used, often with a fluted auxiliary layer designed to deflect lance strikes.

Cuirass
The technical name for the armour's breast- and backplates, the cuirass was one of the core components to any jousting armour. The breastplate was often smoothly angled away from a central apex to deflect blows.

Sabaton
The sabaton was the part of the armour that covered the jouster's foot. They were commonly made from riveted iron plates. Their design varied depending both on the era and the class of the jouster, with high-born members of the aristocracy allowed to sport long tapered sabatons, while the standard gentry were only allowed to wear short, flat-tipped varieties.

allowed were dictated before the tournament Historically, jousting emerged out of the High Middle Ages (1000-1300) and was based on the military use of the lance by heavy cavalry. Up until the 17th Century, jousting gradually evolved from a blood sport into the sporting form of chivalry for which it is now remembered. For example, by the time of Queen Elizabeth I's reign (1558-1603), jousting had been heavily romanticised and was more a form of entertainment, rather than proof of military prowess.

Interestingly, today jousting is seeing something of a renaissance, with dedicated jousting clubs organising competitions and medieval re-enactment events held worldwide.

What was mustard gas?

How did this chemical weapon wreak such devastation?

Mustard gas, a nickname for a variety of sulphur mustard agents, was a class of related cytotoxic (ie toxic to cells) chemical weapons used primarily in World War I and World War II. The agents worked by preventing cellular division within the victim, leading to programmed cell death, DNA damage and, in some cases – where the victim survived the immediate effects – cancer in the long term.

In addition to the direct life-threatening capabilities of the gas, it was also a major irritant to the skin, eyes and respiratory system, leading to large yellow-fluid-filled blisters and chemical burns. Further, the gas had strong mutagenic effects on those it came into contact with, often resulting in severe disfigurement.

The gas was typically delivered onto a battlefield via artillery shells or aerial bombs. Today, the use, production and sale of mustard gas is strictly prohibited and, as such, it is not used in modern conflicts, with existing weapons either strategically destroyed or stockpiled within secure facilities.

A WWI soldier suffering from mustard gas burns

MUSTARD GAS
Smells like GARLIC...
HORSERADISH · MUSTARD

Pallets of stockpiled artillery shells filled with distilled sulphur mustard agent. Inset: A US warning poster from WWII

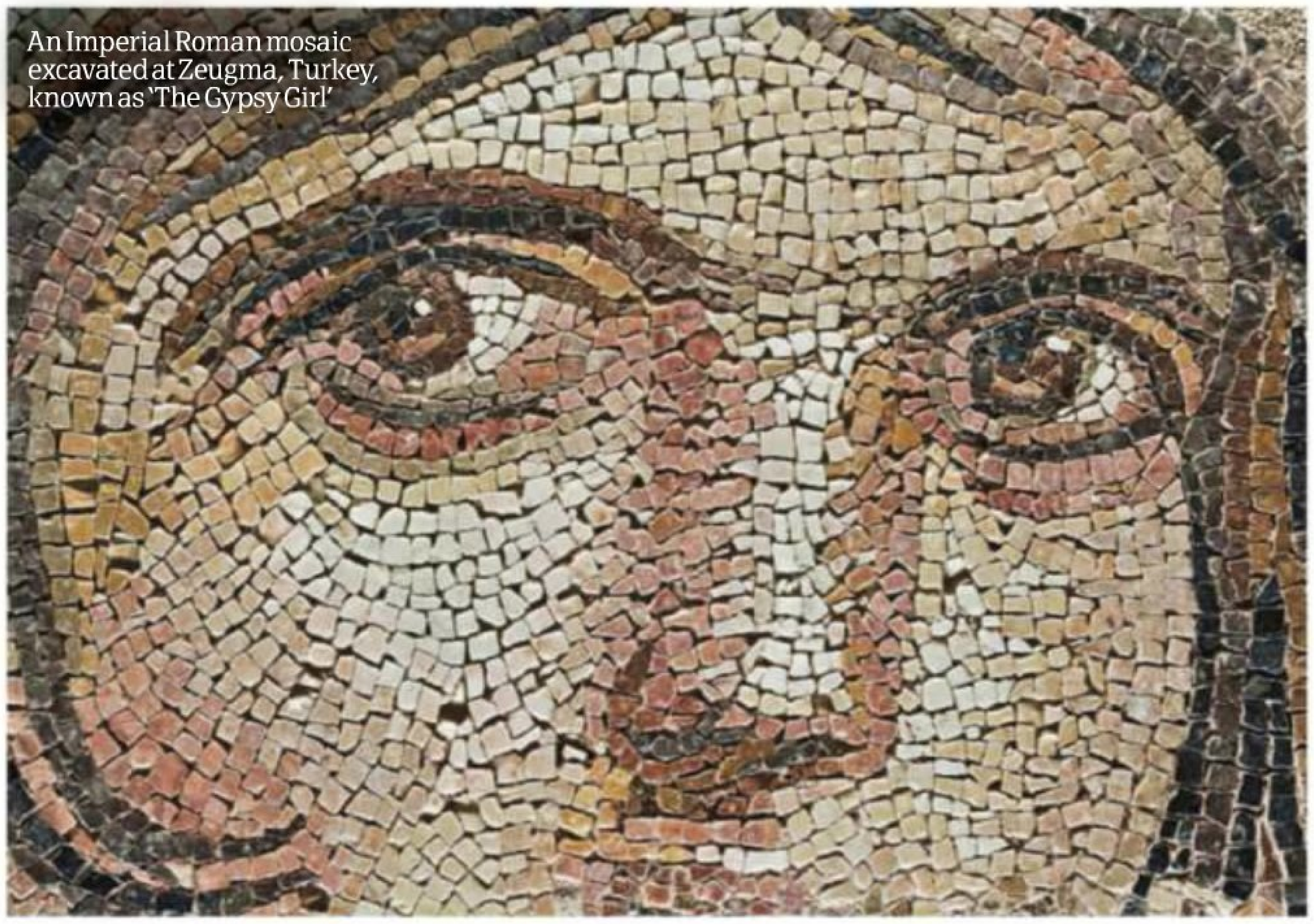
How were mosaics made?

It dates back 5,000 years, but how were mosaics pieced together?

The first examples of decorative mosaics were found in a temple in modern-day Iraq and dated from 3000 BCE. Since that time, civilisations across the world have used mosaics. Romans named individual tiles 'tesserae', which were small pieces of stone, beads or any material that could be arranged to form an image. Colours were achieved using carefully selected stone or shell and, for more elaborate examples, coloured glass and stone coated in gold leaf.

In floor mosaics, a ground layer called statumen was packed with small pebbles onto which 25 centimetres (ten inches) of mortar called rudus was poured. A finer-grade rudus, known as nucleus, was poured on top of that and the design was etched into the surface, before the tesserae were set in place.

Mosaics were applied using one of three techniques: direct application to the surface for 3D objects; indirect application to a backing, before being transferred to a surface; or double indirect, a more complex indirect method in which the tiles could be laid as they would appear in the final work.



An Imperial Roman mosaic excavated at Zeugma, Turkey, known as 'The Gypsy Girl'

How did people sweep chimneys?

Why was this iconic trade of the 19th Century in such high demand?

The occupation of chimney sweeping has often been romanticised, but in reality it was extremely arduous and dangerous work

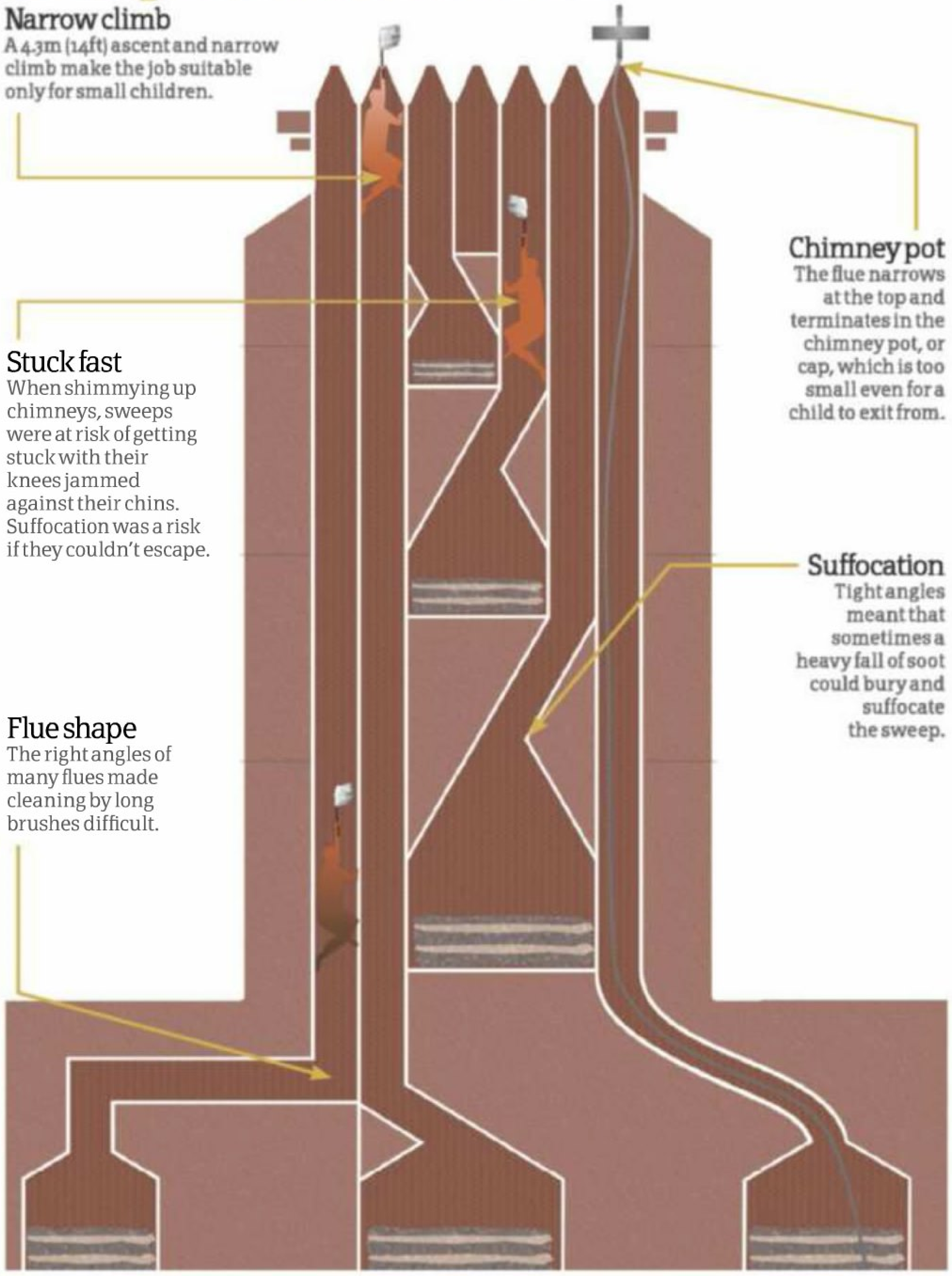
The big cities of the 19th Century – the likes of Paris, London and New York – were grim places to live in many ways. With mains gas and electricity available only in the latter half of the century and only to the well off, heating homes hadn't changed much in centuries. Solid fuels like wood and coal were burned in thousands of fireplaces, belching thick black smoke into the air, the heavier particles of which eventually settled to coat the city in a filmy black layer.

The smoke also coated the inside of the chimney – the flue – in soot and a tarry by-product called creosote. Over time, soot could thicken to the point of blocking the chimney, while the creosote could ignite and send the building up in flames. It was the chimney sweep's job to help prevent this.

A master sweep would take on several apprentices to help him clear the soot with brushes. As the spaces the sweeps had to climb up were often tight – indeed, as little as 23 centimetres (nine inches) wide in places – small boys and girls were chosen. These children – usually orphans from the local workhouse – were bound to the chimney sweep master until they reached adulthood. They would learn how to climb the treacherous bends and ascents of various chimneys and risk their lives on a daily basis. A long brush was used when possible, but often it didn't have the clearance and, besides, the chimney needed to be scraped smooth because the combined soot and flammable creosote content was a saleable commodity in itself.

Four years after London's Great Smog of 1952 – sometimes called the Big Smoke – the Clean Air Act was passed that, for the most part, put an end to the chimney sweep trade.

Occupational hazards



Narrow climb
A 4.3m (14ft) ascent and narrow climb make the job suitable only for small children.

Stuck fast
When shimmying up chimneys, sweeps were at risk of getting stuck with their knees jammed against their chins. Suffocation was a risk if they couldn't escape.

Flue shape
The right angles of many flues made cleaning by long brushes difficult.

Chimney pot
The flue narrows at the top and terminates in the chimney pot, or cap, which is too small even for a child to exit from.

Suffocation
Tight angles meant that sometimes a heavy fall of soot could bury and suffocate the sweep.

A sweep wasn't so lucky…

As well as being ill-treated by their masters and often living in appalling conditions, a chimney sweep's apprentice risked their life every day. Narrow spaces meant they could get stuck, suffocate or fall to their death.

Worse still were the effects of the soot they worked with. Asthma and chest conditions were rife in the occupation, and there was also chimney sweep's cancer, a scrotal squamous-cell carcinoma brought on by sweat accumulating soot around the groin. It produced sores that, in puberty, could invade the testes and eventually move up to the abdomen where it would prove fatal.

The brutality of a chimney sweep apprentice's life was recognised by many peers of the time and, in some places, sending kids up chimneys was forbidden. Regulation finally outlawed the use of children as sweep apprentices in 1875.

© Alamy

How did the Newcomen steam engine work?

Take a look at how this groundbreaking engine worked and how it helped bring about the Industrial Revolution

The Newcomen steam engine – which was named after its inventor Thomas Newcomen – was the world's first practical device designed to harness the power of steam for mechanical work. The first one was built in 1712.

The machine worked by combining the pre-existing technologies of a steam cylinder with a steam-driven piston to raise and lower a pump rod via a balance beam. For a complete mechanical breakdown of the process see the central diagram. The result of this combination enabled Newcomen to create a lifting engine that by simply burning coal could continuously pump large quantities of water out of wells, mines and other reservoirs without the need of manual labour (pumps were usually driven by horse prior to this invention).

Indeed, the relative simplicity of the device and cost-effectiveness when compared to maintaining a stable of animals, in combination with the rapid expansion of England's industry in the early-18th Century, saw the machine surge in popularity, with Newcomen engines installed not just in England, Scotland and Wales but also mainland Europe. In fact, by the mid-18th Century – only 40 or so years after Newcomen invented his engine – there were more than 100 systems in operation. For this reason, and in light of the massive role the steam engine would play in developing British industry, today Newcomen's game-changing invention is seen as one of the primary catalysts of the Industrial Revolution.

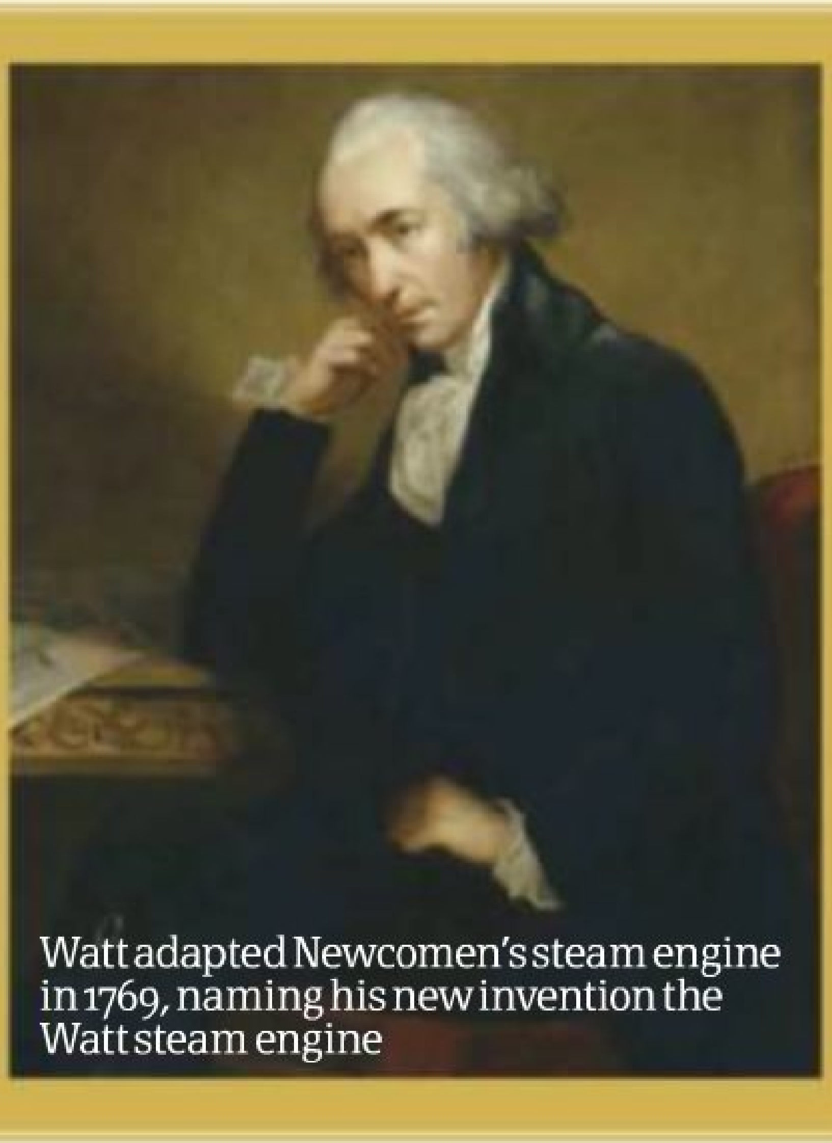
Not surprisingly, however, Newcomen's engine was incredibly crude by modern standards, and indeed those reached by the latter end of the 18th Century. In fact it suffered from a fundamental flaw that was only addressed in 1769. This was that by directly cooling the engine's piston cylinder for each steam cycle, much of the boiler's generated steam was wasted bringing it back up to temperature in the next. This problem was exacerbated by the fact that the larger the Newcomen engine, the larger the cylinder and, as a direct consequence, the more steam was needed to reheat the cylinder. This led to ever-greater quantities of steam to be wasted in the heat-up process and so ever-more coal was burnt to facilitate this.

Regardless of this flaw, the Newcomen engine's ability to transform the power of steam into kinetic energy and mechanical work was a huge milestone in human engineering that played a key role in shaping British industry at this pivotal point in the country's history.

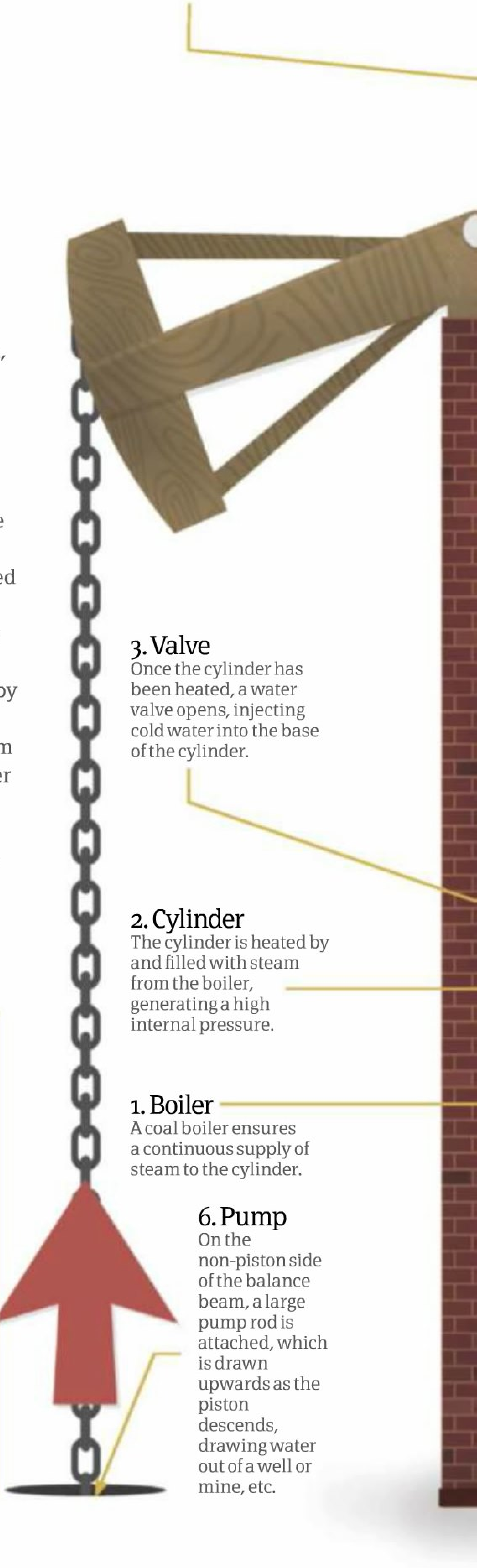
What did Watt do?

Today, James Watt is known as the father of the steam engine, but does he deserve all the credit?

As mentioned, the main problem with Newcomen's steam engine was that it was incredibly costly to operate. This was because each time its central cylinder was cooled to create a vacuum, the cylinder walls remained cold as the next wave of steam was fed in, condensing a proportion of it immediately. This reheating of the cylinder wasted a large quantity of steam, dramatically increasing coal consumption. This problem was solved in 1769 by Scottish engineer James Watt, who realised, while repairing an old Newcomen engine at Glasgow University, that if condensation took place in a separate container attached to the steam cylinder by pipe, the latter could remain hot at all times. Watt proceeded to patent his new steam engine and, despite it being heavily based on Thomas Newcomen's original, avoided paying any royalties by rigorously defending a number of lawsuits personally.



Watt adapted Newcomen's steam engine in 1769, naming his new invention the Watt steam engine



5. Beam
The downward movement of the piston pulls a balance beam down too, via a metal chain. The beam pivots on a central fulcrum.

3. Valve
Once the cylinder has been heated, a water valve opens, injecting cold water into the base of the cylinder.

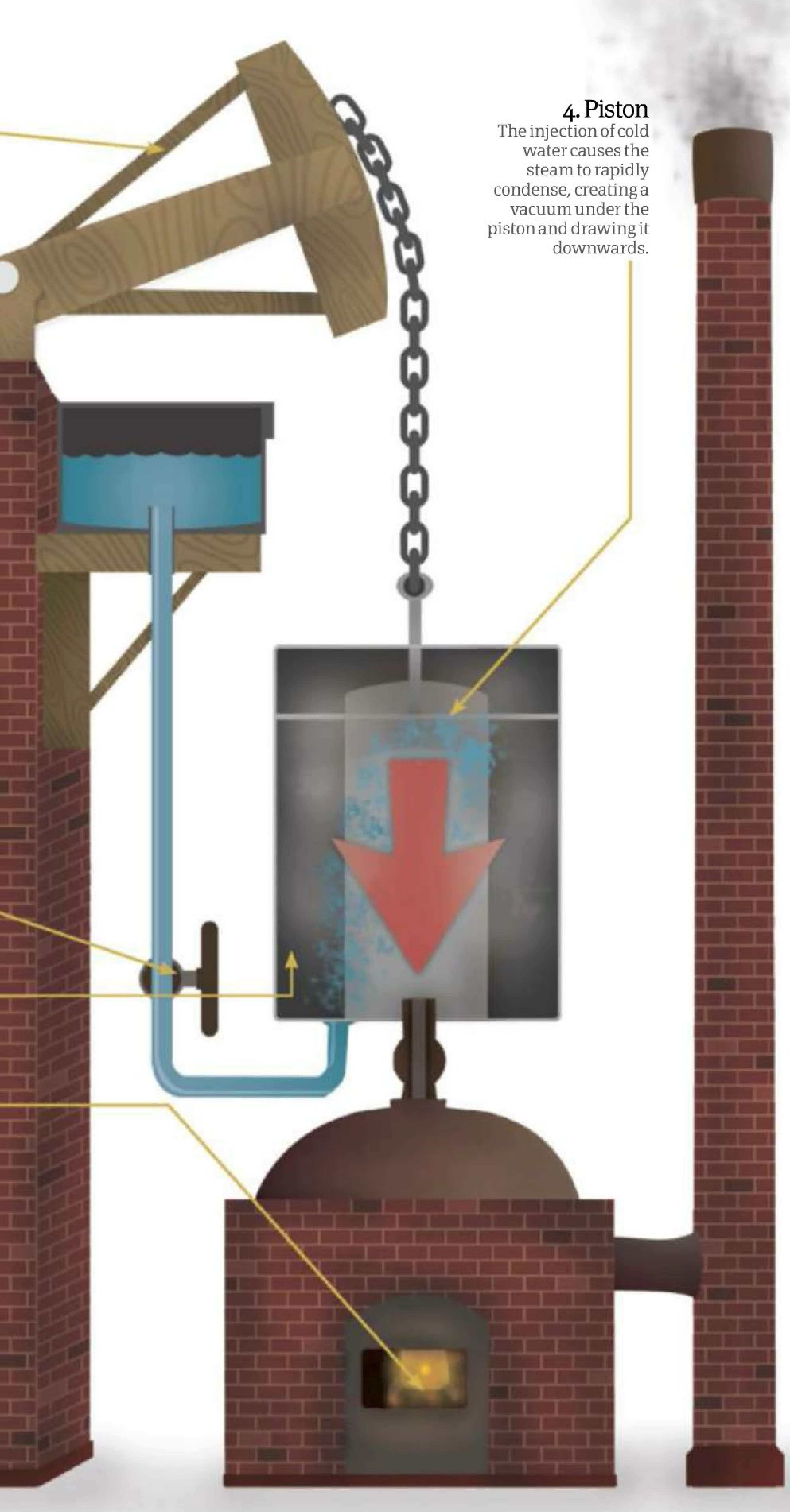
2. Cylinder
The cylinder is heated by and filled with steam from the boiler, generating a high internal pressure.

1. Boiler
A coal boiler ensures a continuous supply of steam to the cylinder.

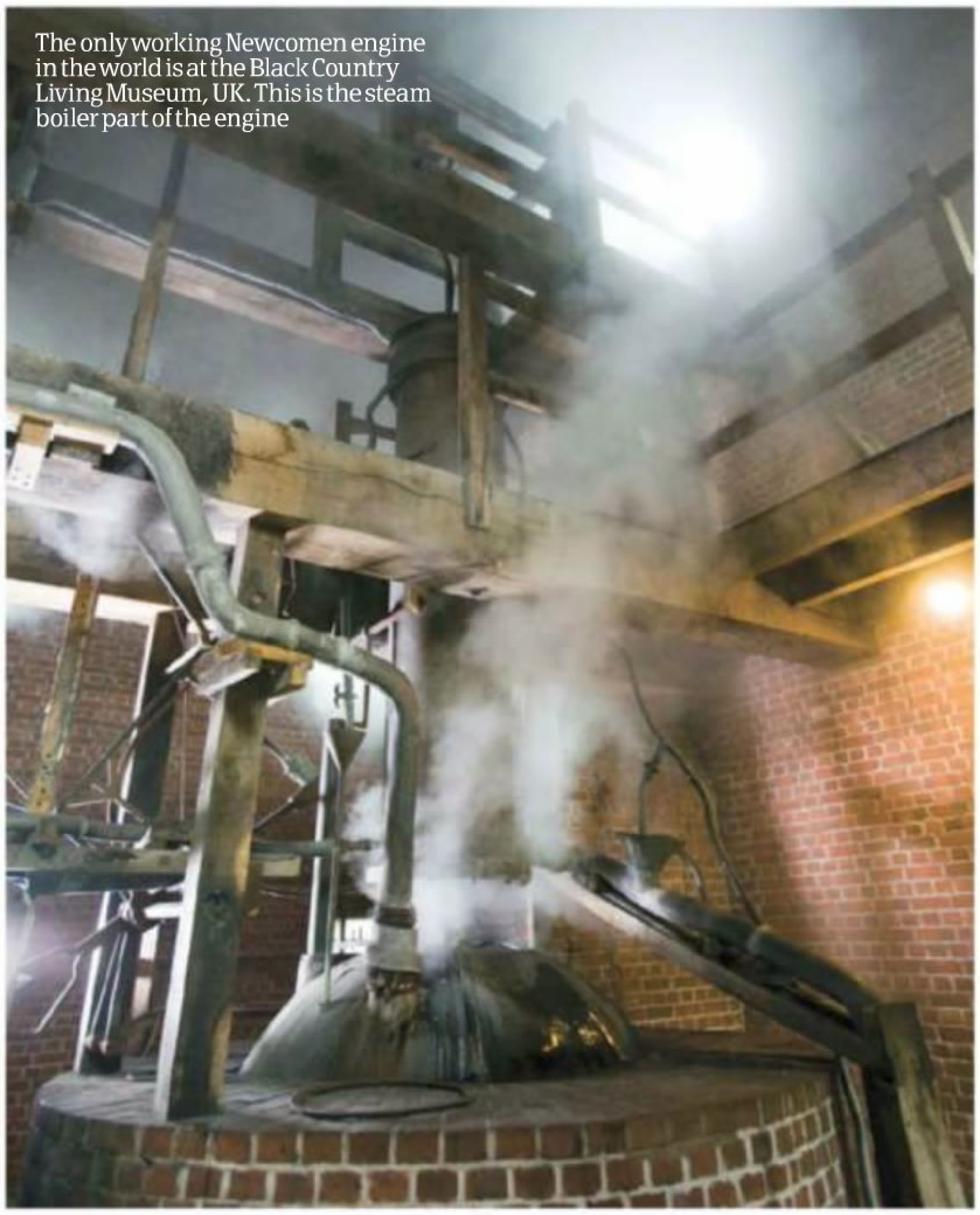
6. Pump
On the non-piston side of the balance beam, a large pump rod is attached, which is drawn upwards as the piston descends, drawing water out of a well or mine, etc.

How did the Newcomen engine generate power?

Follow our step-by-step guide to the workings of this revolutionary piece of machinery



4. Piston
The injection of cold water causes the steam to rapidly condense, creating a vacuum under the piston and drawing it downwards.

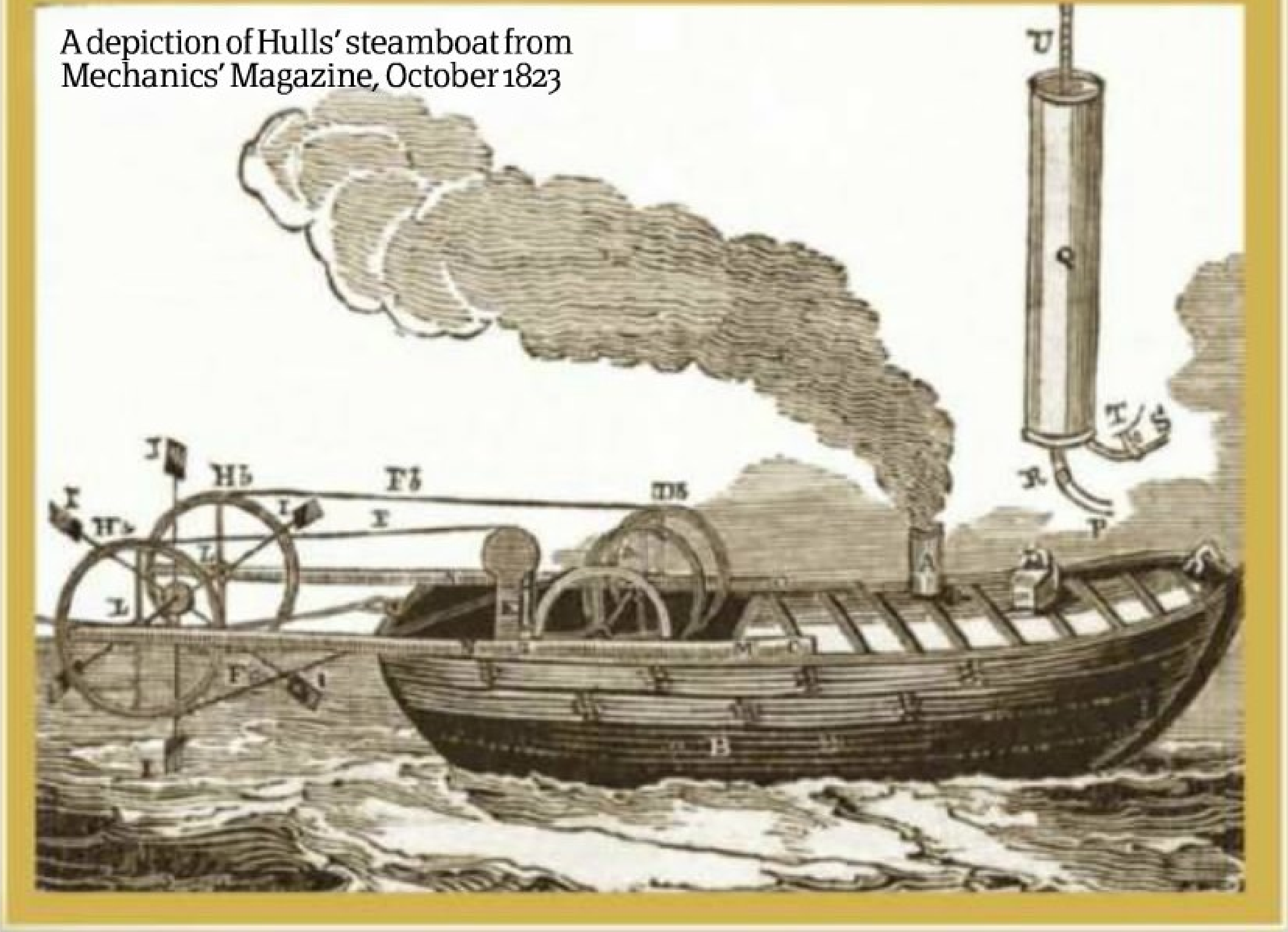


The only working Newcomen engine in the world is at the Black Country Living Museum, UK. This is the steam boiler part of the engine

Hulls' Newcomen steamboat

Although never made, this was one of the first attempts to create a steam-powered vessel

Since their inception, steam engines were increasingly seen as a future means of vehicle propulsion. A good example can be seen in English inventor Jonathan Hulls' design of a steamboat (below), a small vessel powered by a Newcomen engine. Unfortunately, despite being granted a patent for his steamboat in 1736, it was never built as the inefficient and cumbersome engine was thought infeasible. Interestingly, it wasn't until 1774 that a working steamboat was successfully piloted, with the Marquis d'Abbans, Claude-François-Dorothée de Jouffroy, both building and captaining the Palmipède (or 'Webfoot') vessel in Lyon, France.



A depiction of Hulls' steamboat from Mechanics' Magazine, October 1823

2x © SPL

What was the Bathyscaphe Trieste?

A real-life Nautilus, the Bathyscaphe Trieste explored the deepest parts of Earth's oceans, remaining to this day the only manned vehicle to have reached the bottom of the Mariana Trench in the Pacific

After passing 9,000 metres (30,000 feet), one of the Plexiglas windows cracked. Over 1,000 atmospheres – a pressure over six tons per square inch – relentlessly bore down upon the Bathyscaphe Trieste. The hull shook violently, threatening to collapse under the mighty strain. If fractured on even a microscopic scale, the weight of the Earth's deepest ocean would rip the vessel in two, triggering explosive decompression and instantly killing both oceanographer Jacques Piccard and pilot Lieutenant Don Walsh of the US Navy. 23 January 1960, however, was not their day to die. The men had still not reached the bottom of the Mariana Trench's Challenger Deep; the structure had to hold – there was no plan B.

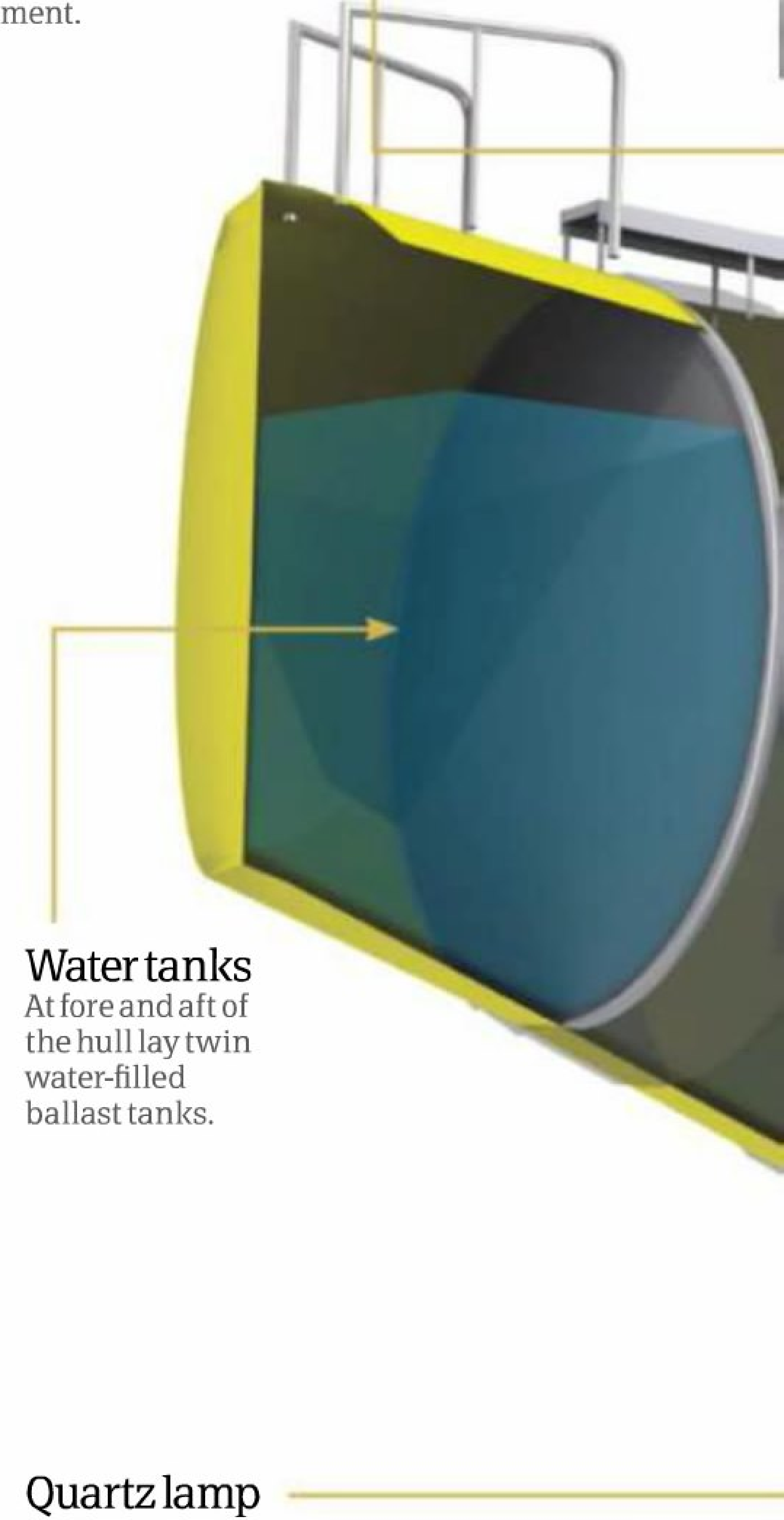
Descending further into the void, cut off from the outside world – the sonar/hydrophone communications system had packed up hours ago – the Trieste continued to dump iron pellets into its ballast system. After all, you don't descend vertically nine kilometres (nearly six miles) beneath the surface of the ocean only to quit so close to your goal. Then finally, out of nowhere and after four hours and 48 minutes within a two-metre (seven-foot) pressurised sphere, Piccard, Walsh and the Trieste touched down. Clouds of diatomaceous ooze (made of the skeletons of dead sea-creatures) diffused from the seabed on contact, filling the surrounding water with a liquidated organic haze.

Half an hour later, after periodically observing this alien environment with high-powered quartz arc-light lamps – periodically as when activated they caused the water to violently boil – and discovering a multitude of life including a white flatfish, several shrimp and jellyfish, Piccard initiated the Trieste's ascent. The vessel had held, but at a depth of 10,916 metres (35,814 feet) the temperature of the pressure sphere was dropping continuously (the minimum recorded was just seven degrees Celsius/45 degrees Fahrenheit); if they were not careful, there would be no return for the vessel and its crew. Three hours and 15 minutes later, the Trieste re-emerged into the daylight and human civilisation. The vessel and its crew had been to a world only envisioned in fiction and returned with field-changing information.

Key to the data gathered was establishing the existence of life at the bottom of Earth's deepest ocean. This revealed that not only were there creatures impervious to extreme atmospheric pressures, but also that water at this depth wasn't stagnant.

This was a clear indication that ocean currents even penetrated these extreme depths, meaning that they should not be used as a dumping ground for radioactive waste. Unfortunately, despite this first-hand evidence, dumping of this kind still continues throughout large parts of the world to this day.

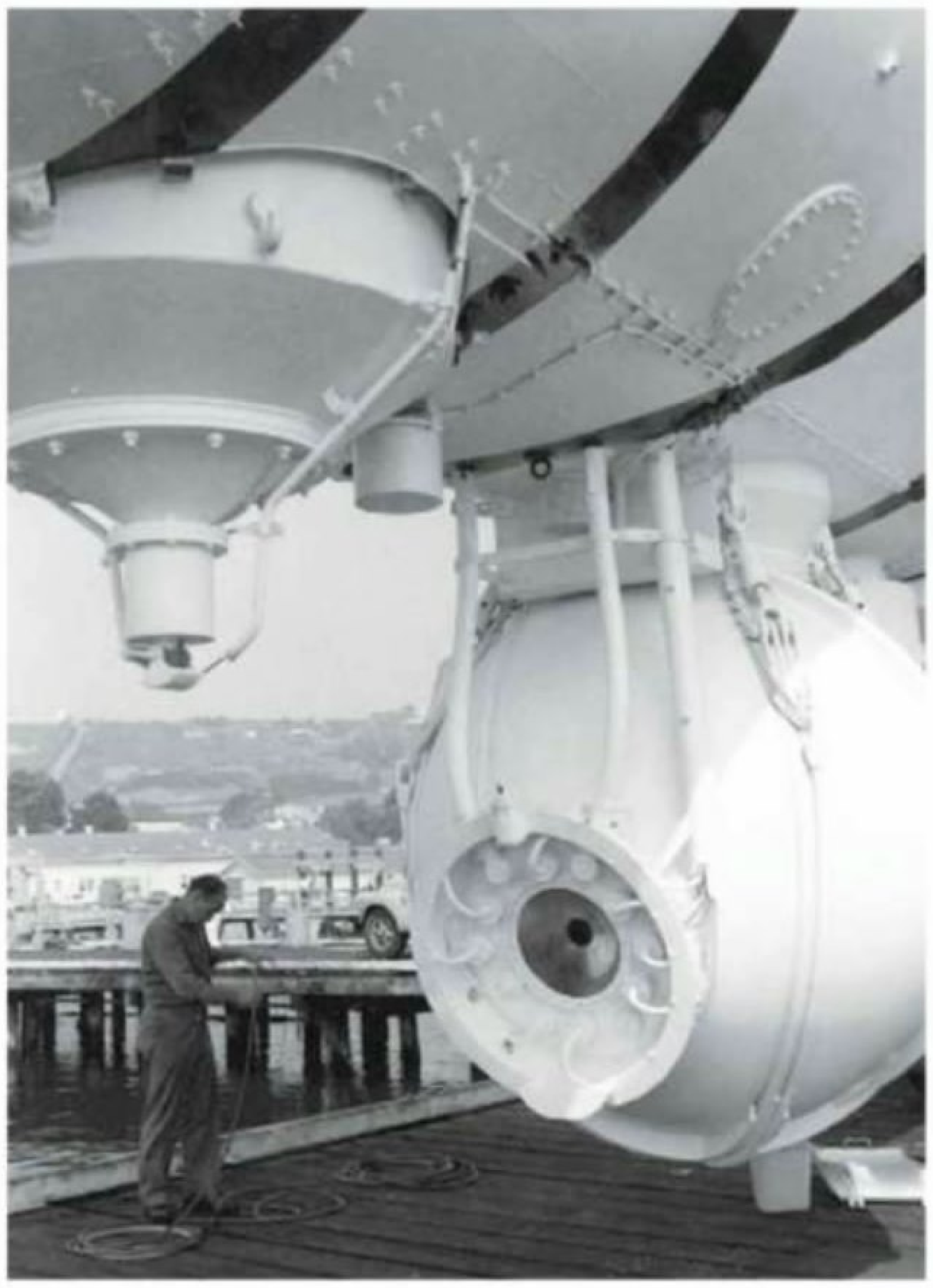
Today the legacy of the Trieste is being built upon, with numerous programmes currently underway focused on designing new vehicles to return to this uncharted territory. The most high profile of these is Richard Branson's Virgin Oceanic, which intends to return to the bottom of the Mariana Trench.



Propellers
The Trieste could largely only move up and down on a vertical plane. However, small, top-mounted propellers allowed a little horizontal movement.

Water tanks
At fore and aft of the hull lay twin water-filled ballast tanks.

Quartz lamp
High-powered quartz arc-light lamps enabled the Trieste's crew to observe their immediate environment. These were mounted to the bottom of the hull.



A close-up view of the Trieste's pressure sphere, clearly showing the Plexiglas observation window and instrument leads

Inside the Bathyscaphe Trieste

A look at the machinery and technology that enabled this record-breaking dive

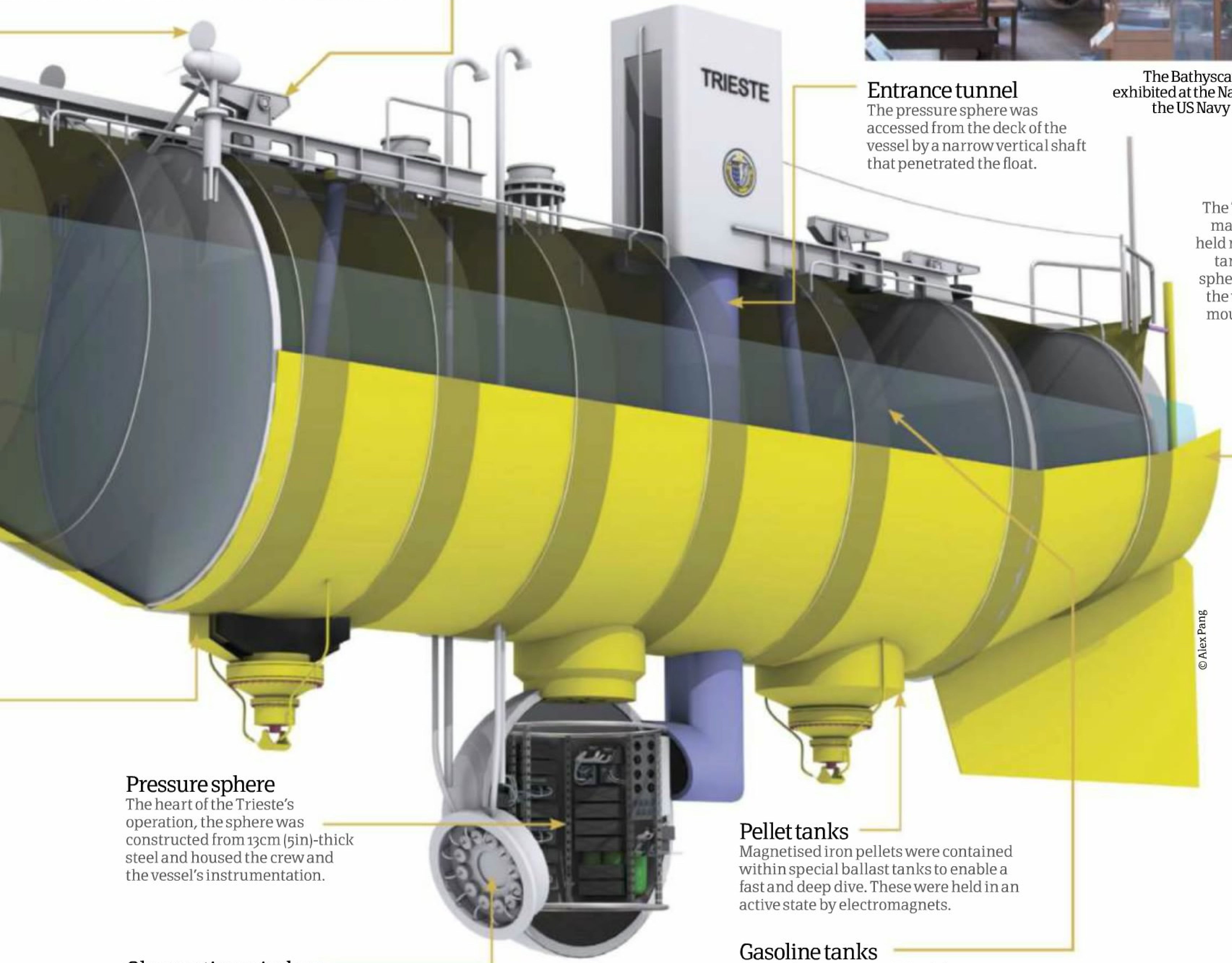
One of the specially designed ballast tanks which worked with magnetised iron pellets

Electromagnets
The magnetic iron pellets that allowed the Trieste to descend so deep were held in place actively by large electromagnets. As such, if there was an electrical failure, the vessel would automatically begin to rise.

The Bathyscaphe Trieste is now exhibited at the National Museum of the US Navy in Washington DC

Entrance tunnel
The pressure sphere was accessed from the deck of the vessel by a narrow vertical shaft that penetrated the float.

Hull
The Trieste's hull was made from steel and held numerous ballast tanks. The pressure sphere that contained the vessel's crew was mounted centrally to its belly.



© Alex Pang

Pressure sphere
The heart of the Trieste's operation, the sphere was constructed from 13cm (5in)-thick steel and housed the crew and the vessel's instrumentation.

Observation window
The only transparent material on the entire craft, the observation window was made from a cone-shaped block of shatterproof Plexiglas (acrylic glass).

Pellet tanks
Magnetised iron pellets were contained within special ballast tanks to enable a fast and deep dive. These were held in an active state by electromagnets.

Gasoline tanks
Due to the extreme weight of the pressure sphere, large gasoline-filled tanks were used to ensure neutral buoyancy. Gasoline was chosen as it is relatively incompressible at extreme pressures.

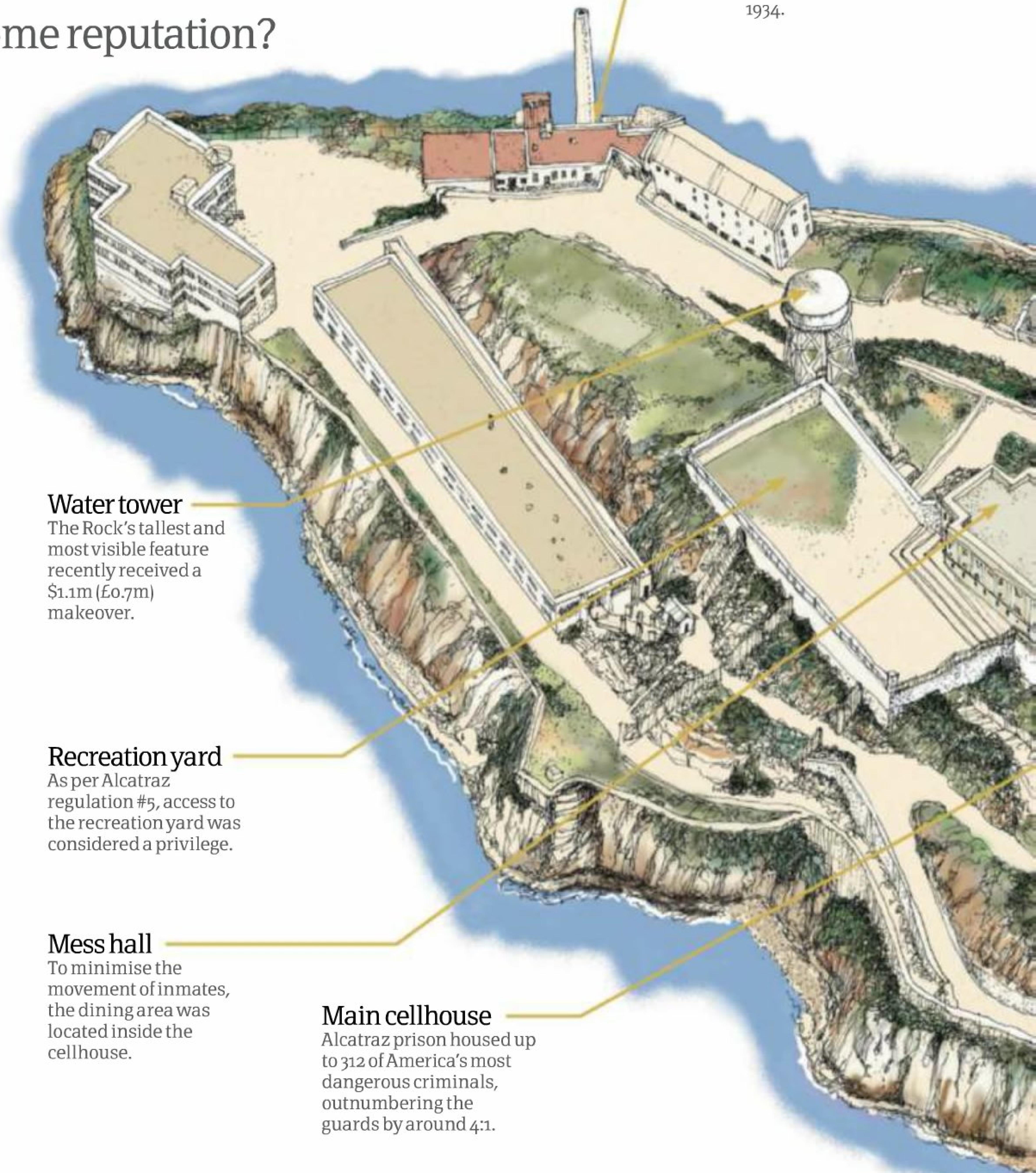
What made Alcatraz prison so secure?

How did The Rock earn its fearsome reputation?

Even when it was named La Isla de Los Alcatraces in 1775, no one had anything nice to say about this nine-hectare (22-acre) island. It was barren, with hardly any soil or vegetation, no beaches, and a layer of guano coated its surface. The stratified rock made it difficult for people to build on and steep cliffs encircled by deadly currents made access a nightmare. It remained untouched for nearly another century before the US began to see the features for which the island had been shunned in a more positive light.

In 1859, Camp Alcatraz was established by the US Army as a garrison for 200 soldiers and armaments, but despite enduring the American Civil War, its guns were never fired. Alcatraz proved far more useful as a military prison for deserters, insubordinates and, of course, Confederate sympathisers. A new block was built in 1909, which was modernised into a maximum-security prison when the army turned The Rock over to the Federal Bureau of Prisons in 1934. It's during the following 30-year period that Alcatraz became the most famous penitentiary in American – if not world – history.

Alcatraz gained its reputation because of its geographical location, its maximum-security status and its notorious inmates. Only 300 of the most disruptive and high-risk of federal prisoners were detained there, held under conditions so strict that anything other than food, medicine, shelter, legal representation and letters to family was considered a privilege to be earned by good behaviour. Security was extremely tight; only the elite of officers were posted at Alcatraz and prison procedures were run with military precision. Even if an inmate did manage to breach the walls, they still had a chilly stretch of water with treacherously strong currents to navigate before they were able to reach the mainland. Alcatraz prison was closed in 1963 after a review concluded that operations were too expensive and its novel location had encouraged a 'circus' atmosphere.



Powerhouse
The military prison had a maintenance tunnel that led from the cellhouse to the powerhouse. This was sealed by the prison authorities in 1934.

Water tower
The Rock's tallest and most visible feature recently received a $1.1m (£0.7m) makeover.

Recreation yard
As per Alcatraz regulation #5, access to the recreation yard was considered a privilege.

Mess hall
To minimise the movement of inmates, the dining area was located inside the cellhouse.

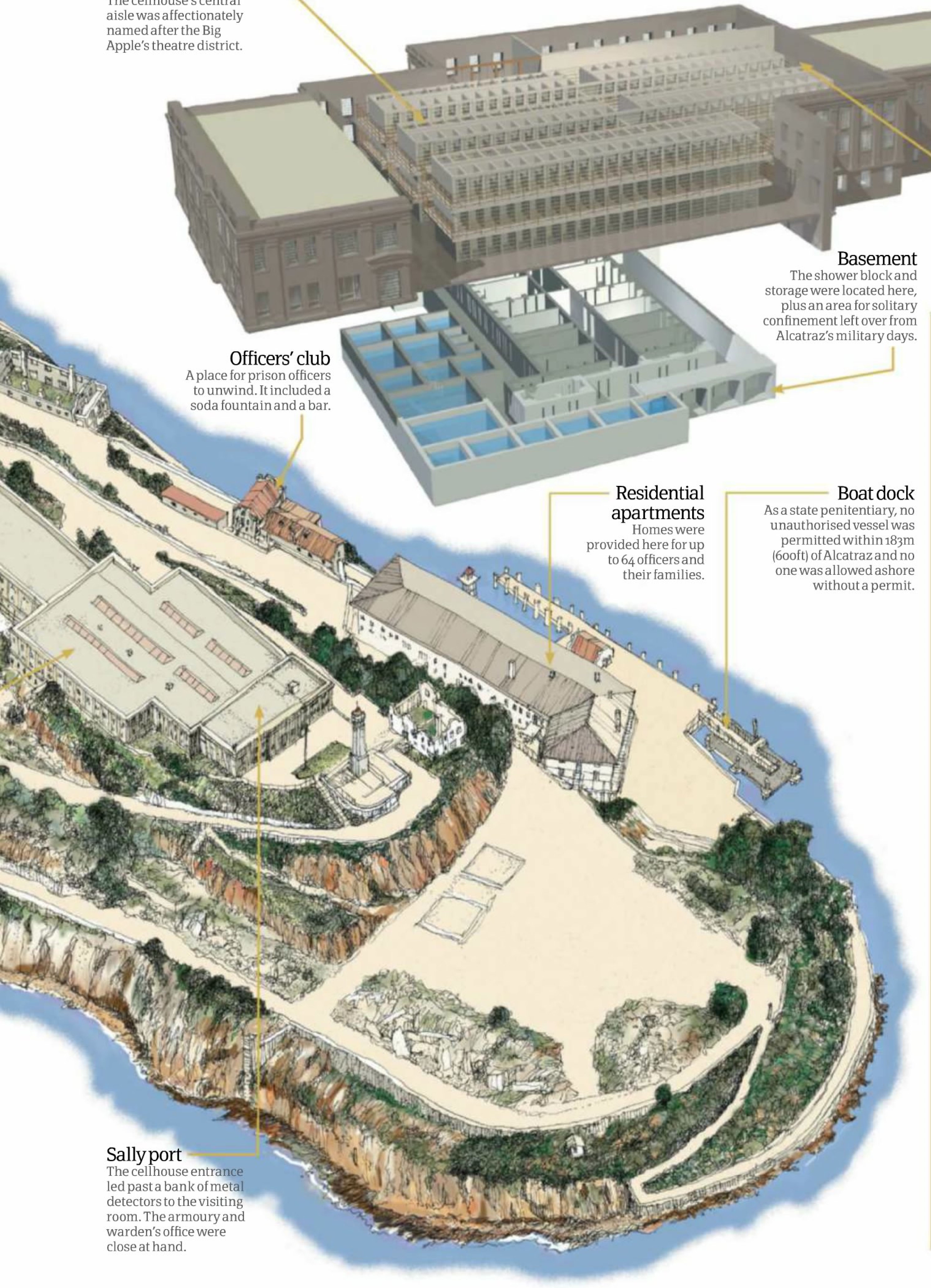
Main cellhouse
Alcatraz prison housed up to 312 of America's most dangerous criminals, outnumbering the guards by around 4:1.

No one escapes from The Rock…

Busting out of this max-security island prison was no mean feat

Over its three decades of operation, 36 prisoners made 14 escape attempts from Alcatraz, of which only five got away and all of these were presumed drowned. One of the better-known attempts was the 1946 'Blastout', where six inmates overpowered a guard, broke into the gun gallery and seized control of the cellhouse, from which they discovered they couldn't escape. A siege ensued that lasted for two days and cumulated in a gun battle with the guards, aided by the US marines, who dropped grenades into the cellhouse to recapture it.

But perhaps the most famous attempt was depicted by the Clint Eastwood film *Escape From Alcatraz*. It was notable for its ingenuity. In 1962 Frank Morris and brothers John and Clarence Anglin used crudely fashioned tools to bore their way into the utility cavity behind their cells. They covered the holes with paintings, built rafts out of raincoats and modelled dummy heads with scraps of soap to avert suspicion until the morning. They were never found and, though presumed dead, they are still wanted by the FBI.



'Broadway'
The cellhouse's central aisle was affectionately named after the Big Apple's theatre district.

Gun galleries
Guards on the floor weren't allowed firearms. Instead, officers armed with rifles controlled the floor from these secure balconies.

Basement
The shower block and storage were located here, plus an area for solitary confinement left over from Alcatraz's military days.

Officers' club
A place for prison officers to unwind. It included a soda fountain and a bar.

Residential apartments
Homes were provided here for up to 64 officers and their families.

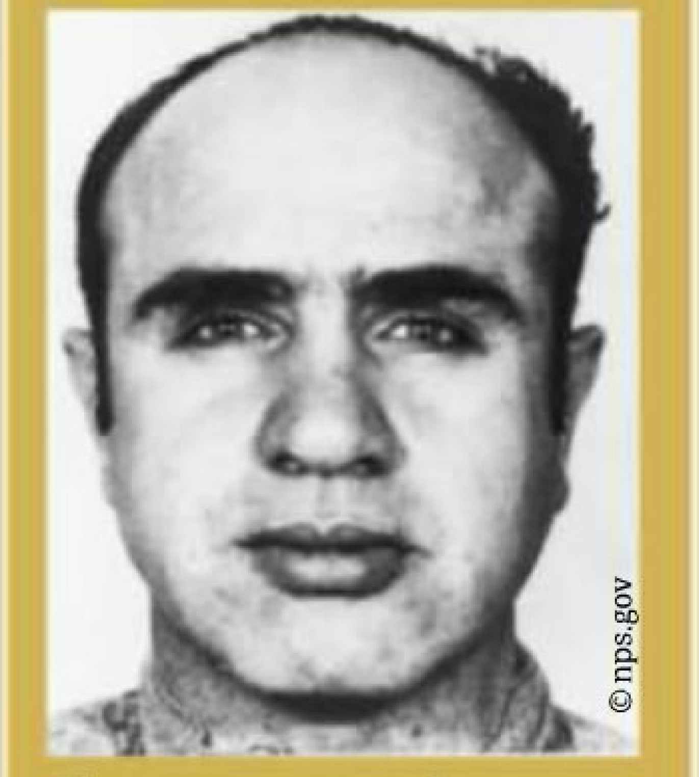
Boat dock
As a state penitentiary, no unauthorised vessel was permitted within 183m (600ft) of Alcatraz and no one was allowed ashore without a permit.

Sally port
The cellhouse entrance led past a bank of metal detectors to the visiting room. The armoury and warden's office were close at hand.

Rogues' gallery

Alcatraz was designed to house America's most notorious and dangerous criminals, partly to isolate the highest-profile inmates from influencing residents in other prisons and partly to stand as a high-visibility example. Alcatraz's most infamous inmate was Chicago underworld kingpin Al Capone, who terrorised parts of the US between the Twenties and early-Thirties. He was incarcerated at Alcatraz in 1934 and transferred to Terminal Island Correctional Institution in 1939, with a fraction of the influence he had during the Prohibition era.

Other notable criminals who succumbed to the full force of the US penal system included kidnapper George 'Machine Gun' Kelly, Bonnie and Clyde accomplice and bank robber Floyd Hamilton, Ma Barker gang member Alvin 'Creepy' Karpis and murderer Robert 'Birdman' Stroud, who was portrayed in the 1962 film classic *The Birdman Of Alcatraz* by Burt Lancaster.



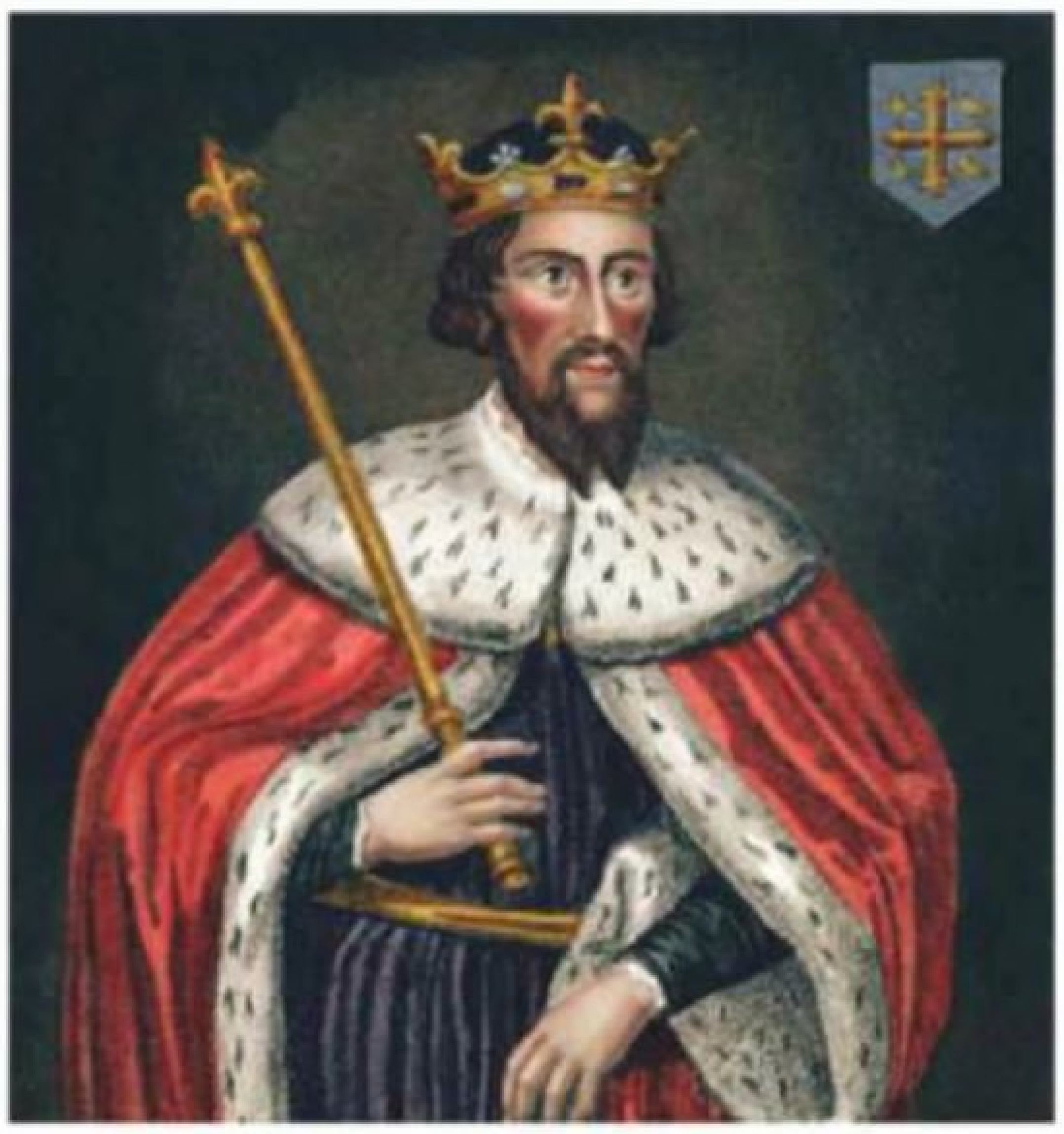
© nps.gov

The notorious crime boss Al Capone served just over six years at Alcatraz

2x illustration © Ormsby and Thickstun Interpretive Design

Who was the first ever king and queen of England?

Some historians think the beautiful, but wicked, Aelfthryth (c.945-1000) was the first queen of England, while others believe Matilda (c.1102-1167), the daughter of King Henry I, was the first female monarch. Queen Mary I (1516-1558), aka Bloody Mary after burning many religious opponents at the stake, was officially anointed and crowned, so is generally recognised as the first woman to rule. Early kings of England include Athelstan (c.895-939) whose victories over the Vikings and the Scots meant he was crowned first king of a united England. However, to complicate matters, his grandfather, Alfred the Great (c.849–899; pictured below), was the first to be crowned King of the English.



What caused the great Irish potato famine?

The famine was caused by a fungal disease called potato blight, which came to Ireland from Mexico. Blight made the potatoes quickly rot, and since a third to one-half of peasants were dependent on the crop for food, this led to more than 750,000 deaths. But the famine was also the result of the social and political system in the 1840s. As Irish Catholics could not own land or hold a profession, the peasants resorted to growing mostly potatoes – which could be grown in large quantities on plots of rented land – to feed their families.

What is the Terracotta Army?

The Terracotta Army, unearthed in 1974, is one of the most exciting archaeological finds in recent history. The figures represent the soldiers of Qin Shi Huang, the first emperor of China. They had been placed in his tomb, an earthen pyramid mound, which was excavated beneath Mount Li. Construction had begun when the emperor was a child – it took many years to build. The tomb represents the royal palace, and the figures inside, court residents. Beside the warriors, archaeologists found models of officials and entertainers. There are 8,000 soldiers, each depicted with weapons such as spears, bows and arrows. There are also models of horses and chariots. Made out of yellow clay, the Terracotta Warriors were meant to protect the emperor in the afterlife. Artisans first made the limbs and heads which were then fired in a kiln.

Once assembled, the models were painted and coated with a preservative, but only some colours are still visible. Each figure was given individual features, with details added to the hair and clothes; artists even added muscle tone to the arms and legs. The height of the soldier depended on his rank – ie the military generals are the tallest figures in the group.

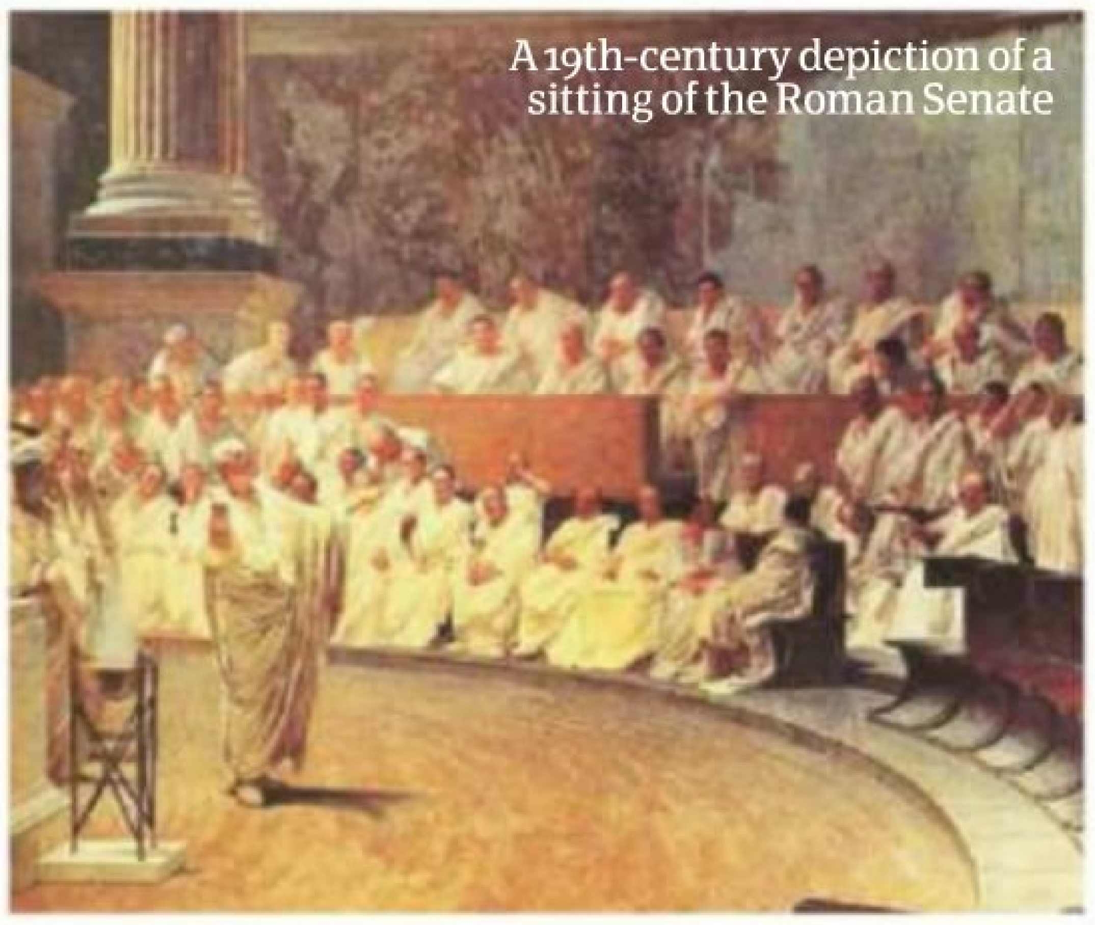
What was the role of the Roman Senate and how did it operate?

The Senate was tightly controlled by the Roman emperors, so to answer this question we'll concentrate on the Roman Republic. The Senate was the supreme council of the Roman state and anyone with any importance would have belonged to it.

Basically entry depended on having been elected to one of the annually appointed posts in the Roman government and administration, eg the consulship. Normally a few years would have gone by before a man could expect to join. Membership was for the most important men in Rome from well-to-do families who possessed the most wealth and influence within this community.

Membership was for life unless expelled for misbehaviour. It was the annually elected magistrates who ran the government but the Senate gave formal advice and it was up to a consul to enforce it. It was an advisory body, which held tremendous authority. It could extend some magistrates' time in office.

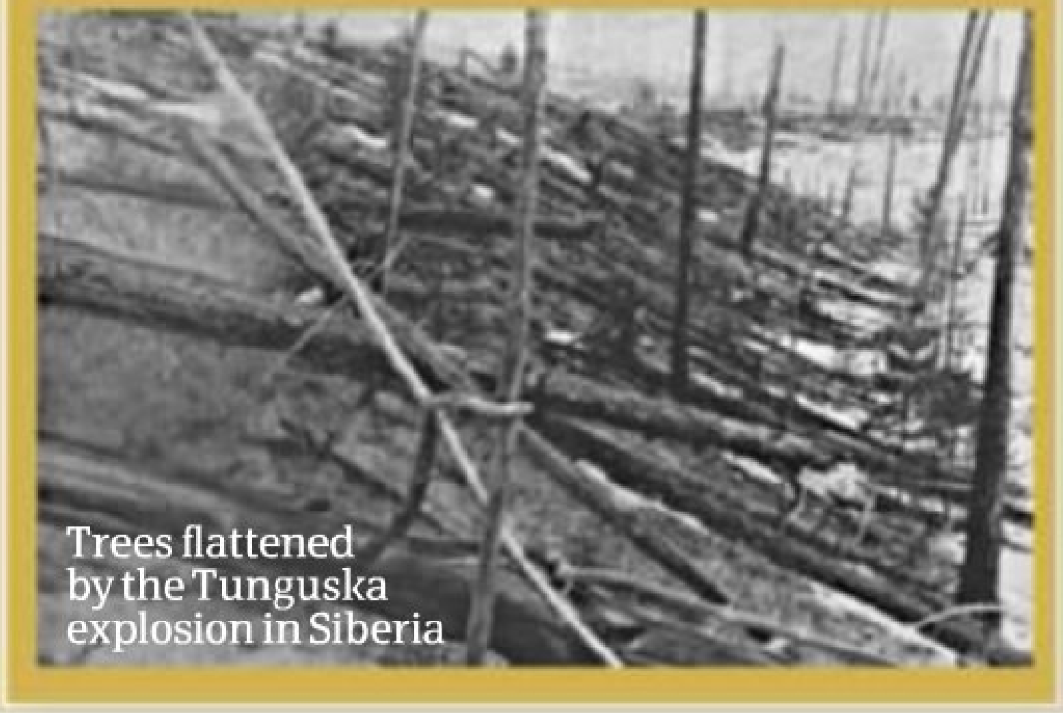
During the Second Punic War (which took place from 218-201 BCE) the Senate made crucial strategic decisions and handled the war-effort, which essentially led to the defeat of Hannibal and Carthage. The little-remembered Second Punic War is one of the most famous victories in the history of ancient Roman warfare.



A 19th-century depiction of a sitting of the Roman Senate

What caused the Tunguska impact back in 1908?

The Tunguska explosion was caused by an extremely large object that detonated in an airburst five to ten kilometres (3.1-6.2 miles) above Tunguska, Siberia, in 1908. Scientists still debate whether the object was a meteoroid or a comet fragment. The former would have been a rocky mixture of iron ore and silicon oxides; the latter, mainly ice. The explosion was 1,000 times more powerful than the Hiroshima bomb, so all of the object was vaporised.


Trees flattened by the Tunguska explosion in Siberia

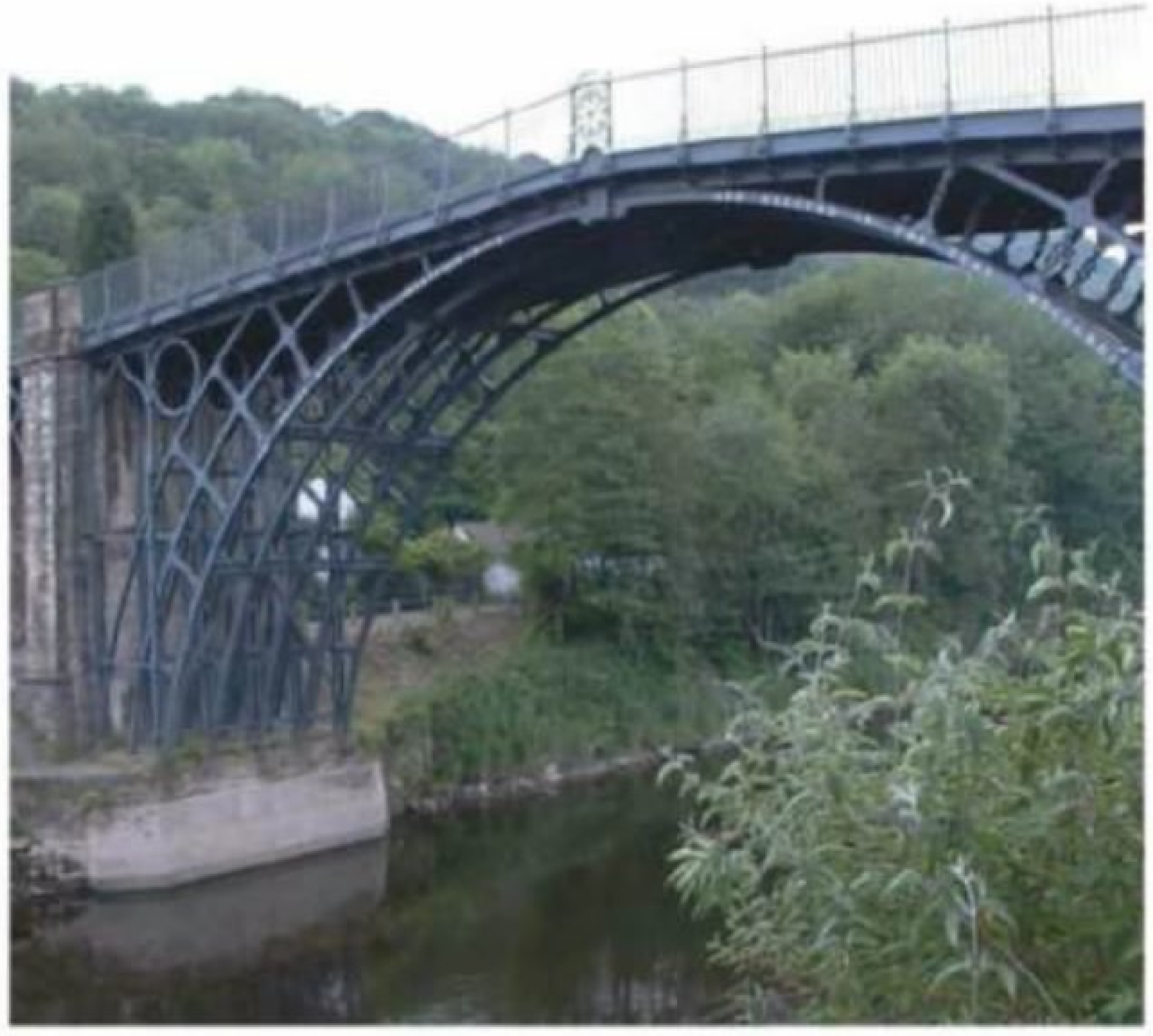
Who made the first QWERTY keyboard?

Modern keyboards are based on the system devised for the very first typewriter, patented in 1873 by the Milwaukee printer Christopher Latham Sholes. His model used a piano-style keyboard of two rows of keys arranged alphabetically. This ran into problems when the metal typebars linked to the keys jammed if pressed too quickly. The solution was to separate commonly used letter pairs like 'th' so the typebars jammed less often. This system was called QWERTY, after the first letters of the top row. This was intended to help typists work more efficiently. After Remington picked up the manufacturing rights to Sholes' typewriter, the QWERTY system was continually modified, shifting the position of less important keys and adding new ones. The QWERTY system took on a new life with the advent of electronic typewriters. IBM adopted it in the Sixties for its first PC keyboards. There have been many improvement and addition to it since then.

What is so special about Shropshire's Iron Bridge?

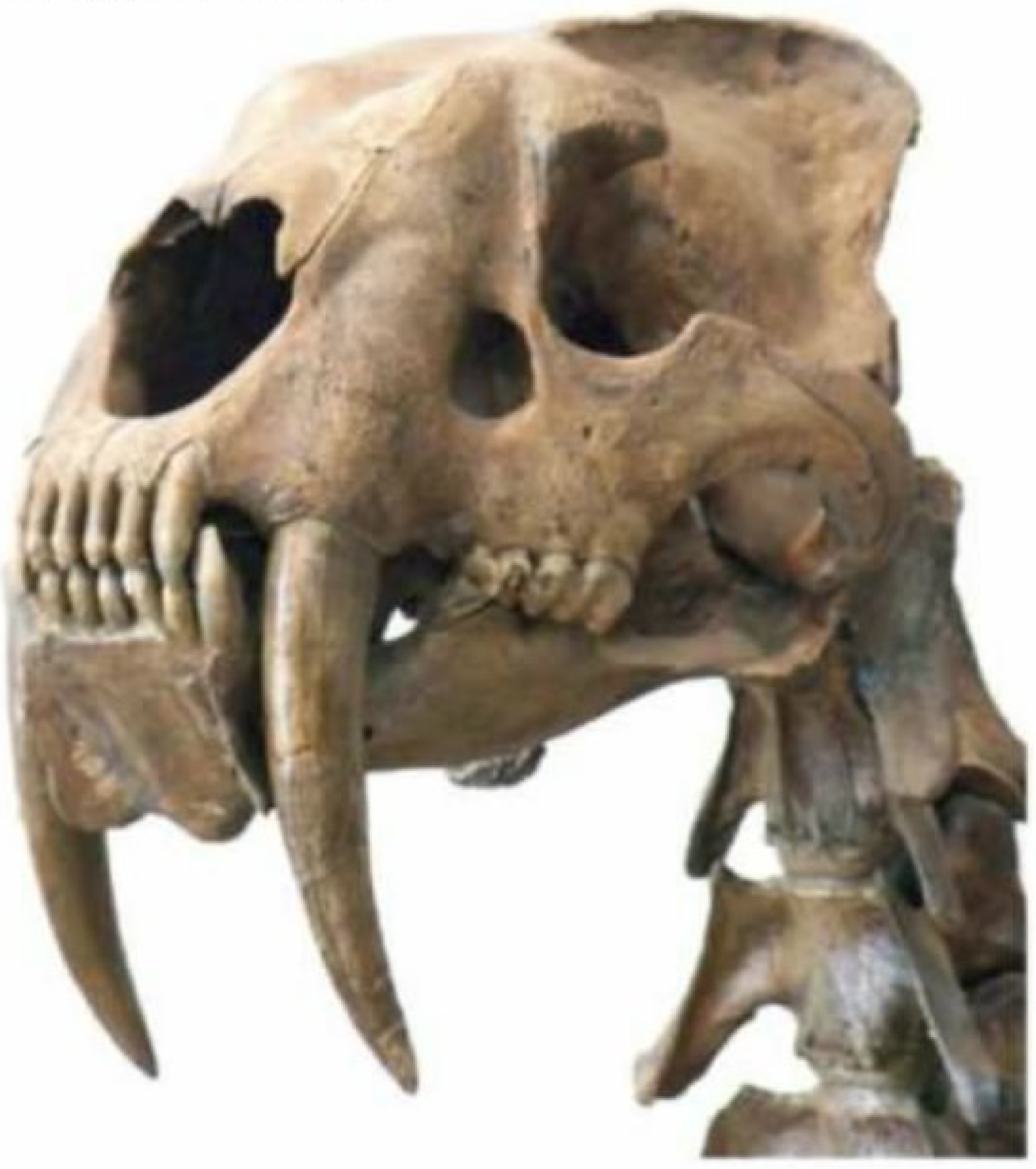
The town of Coalbrookdale might seem an unlikely choice for a construction that came to define Britain's industrial potential, but in the 18th Century it was a very different place. Shropshire was one of the UK's leading producers of coal, but only six ferry crossings in the immediate area. As a result, in 1779 a team of entrepreneurs led by architect Thomas Farnolls Pritchard, proposed initial designs for what came to be the world's first cast iron bridge.

Needing to span 120ft of the River Severn with a single arch, it cost around £6,000 (over £1.5 million in today's money). It also went through several designs before Pritchard died a month into its construction.



How long were sabre-toothed tigers' teeth?

Sabre-toothed tigers were actually sabre-toothed cats, or smilodons, which lived mainly in the Americas and became extinct about 10,000 years ago. Their teeth were between 18-28cm (7-11in) long. It's believed smilodons used their teeth on subdued prey to cut off the blood supply and strangle them. Despite the larger teeth, they had a weaker bite than modern-day big cats but could open their jaws 120 degrees compared to lions whose limit is 60.



What's the biggest archaeological site?

The prehistoric site of Çatalhöyük in Turkey covers about 13 hectares (32 acres), while the Palace of Knossos, Crete, covered an area of about 13,000 square metres (140,000 square feet). Pompeii covers an area of 60 hectares (145 acres) and has been described as 'the most complete urban excavation ever undertaken'. This is tiny in comparison to the ruins of the temple complex of Angkor Wat in Cambodia, which cover up to 3,000 square kilometres (1,160 square miles)!

© Ziggurat

> "The ruins of the temple complex of Angkor Wat in Cambodia covers up to 1,160 square miles"

Who invented Penicillin?

Although French student Ernest Duchesne noted the growth of penicillin in 1896, its true potential was not realised until Scottish scientist Alexander Fleming re-discovered it in 1928. He noticed that colonies of the bacterium Staphylococcus aureus failed to grow in areas of a culture that had been contaminated by the green mold Penicillium notatum. However, its ability to kill infectious bacteria wasn't demonstrated until Dr Howard Florey's research proved it at Oxford University over a decade later.

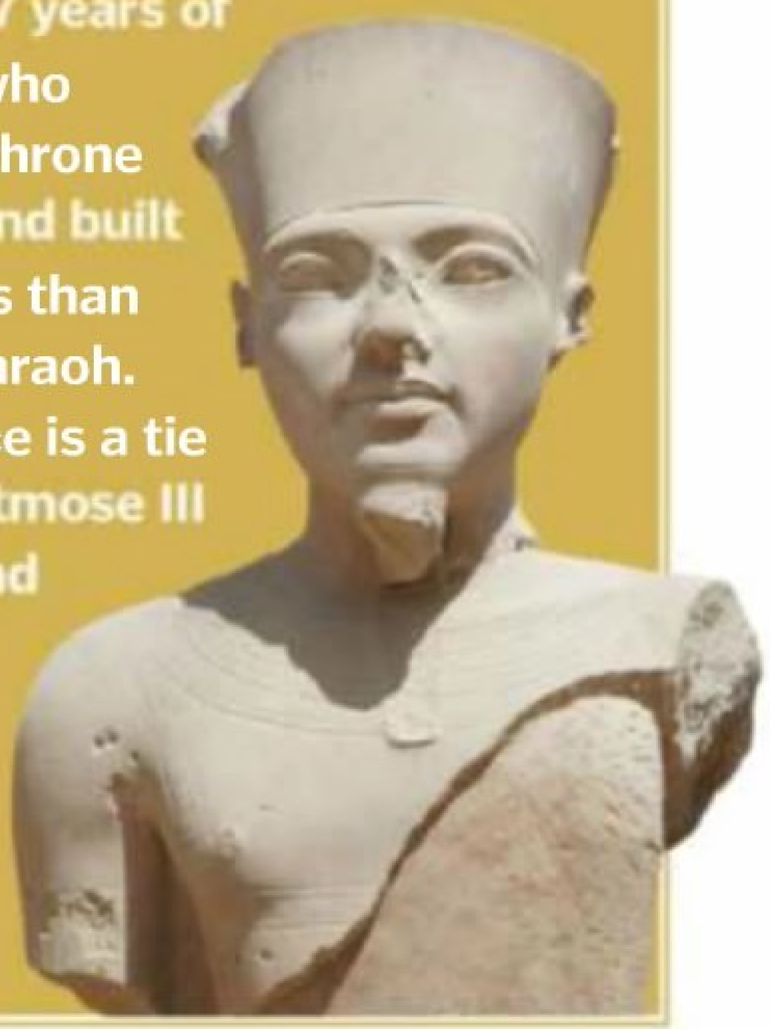
Penicillin, a group of antibiotics, works by inhibiting the bacterial enzymes responsible for cell wall synthesis, while activating additional enzymes to break down the protective wall of the unwanted micro-organism. Consequently, penicillin is effective in combating micro-organisms that produce cell walls, as most bacteria constantly need to remodel their peptidoglycan cell walls as they grow and divide. This involves the pencillin's chemical structure binding to the enzyme that links the peptidoglycan molecules in the cell wall, which inhibits the formation of cell wall cross-links and causes the cell to burst (known as cytolysis) and cell death due to osmotis or water pressure.

Macro photograph of a petri dish culture of the fungus Penicillium notatum, a species of fungus that inhibits bacteria growth

© Science Photo Library

Who was the longest-serving pharaoh of ancient Egypt?

According to later king lists, Pepi II ruled for 94 years around 2200 BCE. However, contemporary documents only go up to the seventh decade of his reign, and it is not certain that he really ruled for that long. The longest fully documented reign is the 67 years of Rameses II, who came to the throne in 1279 BCE and built more temples than any other pharaoh. The next place is a tie between Thutmose III (1479 BCE) and Psamtik I (664 BCE), both of whom ruled for 54 years.



What was the Parthenon in Athens used for?

The Parthenon is the name given to the temple dedicated to the goddess Athena. It stands on the Acropolis in Athens, Greece. It was built 447-432 BC and replaced an earlier unfinished temple that was destroyed by the Persians. It measures about 70m (230ft) by 30m (98ft) and is made of marble. The building project was part of a bigger scheme to beautify Athens initiated by the Athenian politician Pericles. The famous sculptor Phidias created a huge statue of Athena 10.5m (35ft) high for one of the interior spaces of the Parthenon. The statue was made of gold and ivory and held a human-size Goddess of Victory in one hand. The carved stone sculptures that once decorated the temple were removed by Lord Elgin and sold to the British Museum in the 19th Century.

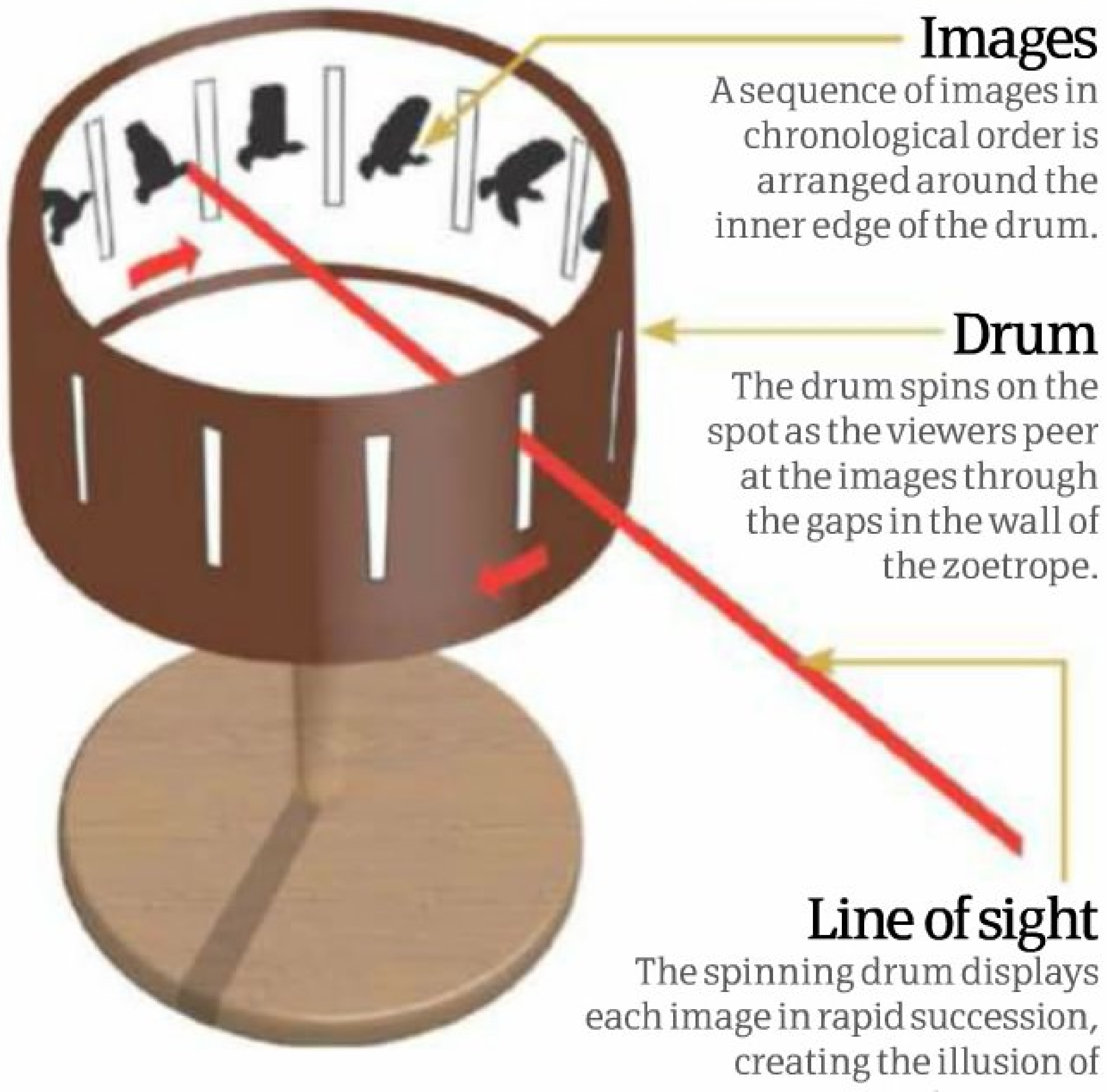
© Science Photo Library

The phi phenomenon accounts for how our brains can interpret a series of still images as a single moving entity

How do zoetropes work?

Today when you go to the cinema or watch TV, what you are actually seeing is a huge number of consecutively photographed images, or frames, displayed one after the other in very close succession. As each frame is individual there is a brief moment between each picture when there is nothing to see. If the series of images can be displayed at a high enough rate, these blanks, or gaps, between two pictures can become so miniscule that the brain does not even register them. Not only that but we can also perceive 'apparent movement' in the images. This is due to an illusion called the phi phenomenon – enabling the mind to bridge the gap between two images.

The zoetrope can help us achieve this psychological illusion by fooling the brain that it's seeing a continuous moving image. The toy features a hollow drum decorated inside with a sequence of stationary images, each one different from the last. Around the edge of the drum are narrow slits through which the viewer can peer. The view through each slit reveals just one image at a time – the one on the opposite side of the drum. When the drum is spun, however, the viewer sees multiple views through multiple slits, giving the impression of steady, continuous movement as the brain fills in the gaps between the pictures and makes it appear as a moving image.



Images
A sequence of images in chronological order is arranged around the inner edge of the drum.

Drum
The drum spins on the spot as the viewers peer at the images through the gaps in the wall of the zoetrope.

Line of sight
The spinning drum displays each image in rapid succession, creating the illusion of movement to the viewer.

When was the last ice age?

There has been a series of ice ages over the past million years or so. Sometimes this whole period is referred to as the 'ice age', although it has included many individual glacial periods that alternated, every 100,000 years or so, with warm periods called interglacials. The 'last ice age' refers to the most recent of these glacial episodes. This started about 100,000 years ago and ended 11,700 years ago. That whole period can be regarded as the last ice age, though it was also complex, with varying climate. The coldest part, when massive glaciers extended as far south as Britain, happened between 25,000 and 20,000 years ago – the last glacial maximum. When will the next ice age be? Past interglacials have been quite variable – ours has lasted 11,700 years. According to geophysicists, our interglacial still has several thousand years left to run, after which another ice age may begin. But human influence could change everything. The climate system is very complex and delicate, and global warming could hugely affect this.

Technology

114 ......How are light trails captured?
116 ......What is one-way glass?
116 ......How does liquid armour stop bullets?
117 ......What's inside a paintball gun?
117 ......How do silencers muffle sound?
118 ......What's inside a sniper rifle?
120 ......How do fire suits protect people?
120 ......What's inside a fire sprinkler?
121 ......How do incubators work?
122 ......What is paper made of?
124 ......How do you send and receive emails?
125 ......How can you make ice cream?
125 ......What keeps computers cool?
126 ......How do breadmakers work?
126 ......What makes tumble dryers dry clothes?
127 ......How can ovens cook food?
128 ......How do self-service checkouts work?
130 ......What is underfloor heating?
130 ......How do saunas stay warm?
131 ......Where are diamonds mined?
132 ......How do water turbines work?
134 ......What is Teflon?
134 ......How do braces straighten teeth?
135 ......What makes Velcro stick?
135 ......Why is Sellotape sticky?
136 ......Why do pressure washers clean so well?
137 ......How do inhalers help asthmatics?
137 ......What's inside a jukebox?
138 ......How can flood barriers protect cities?
140 ......Bitesize Q&A

RCA VIDEO
TP2
C13
C15
RG3
C9
RG1
IC2
P1
Raspberry

AUDIO
USBx2
LAN

How are light trails captured?

How are these bright, abstract streaks of light caught on camera?

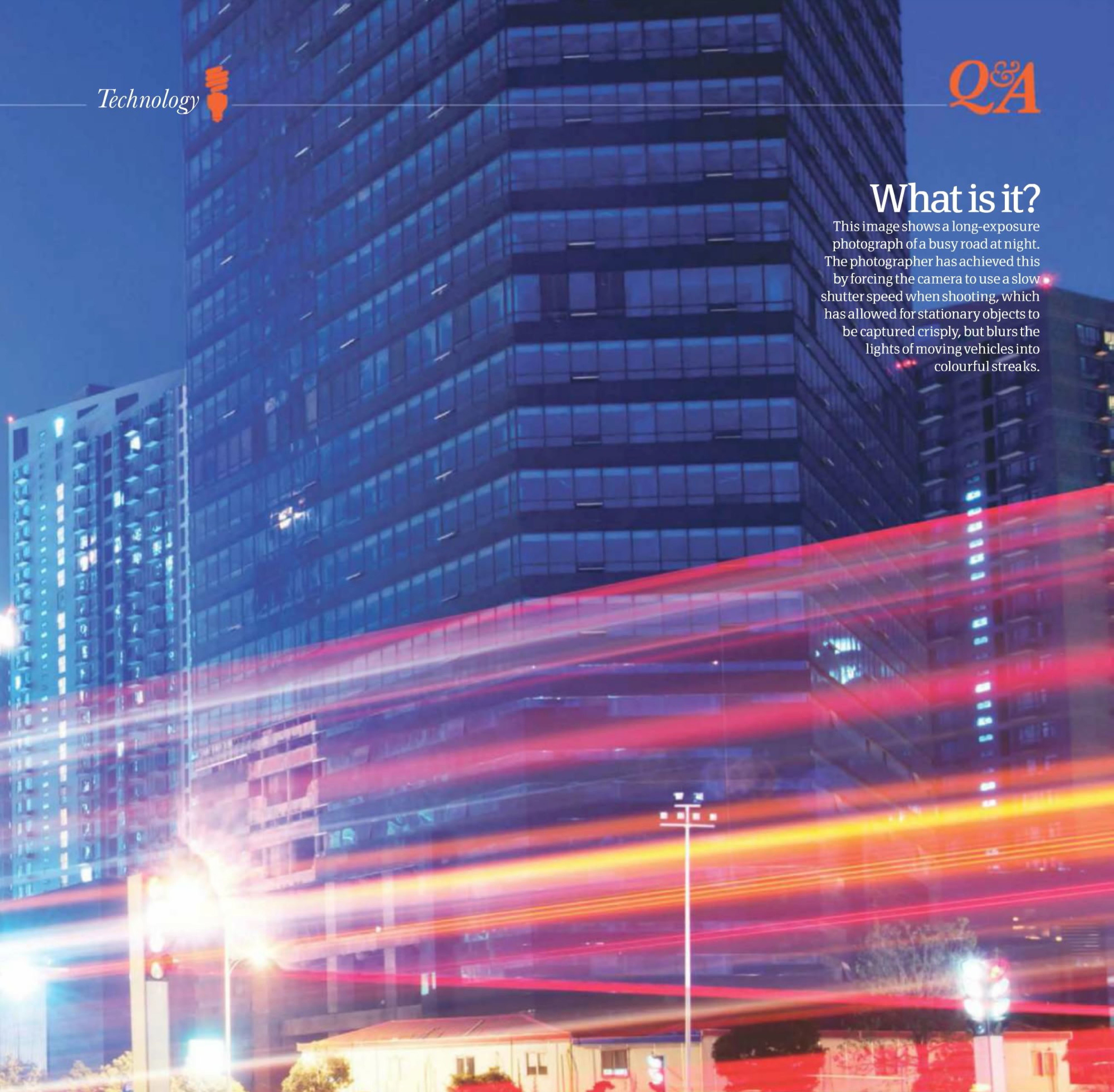
Light trails are a colourful and creative effect that photographers can capture by employing long-exposure shooting on their camera. The basic principle of light trail creation is that by manually dropping a camera's shutter speed to a very low level, light is captured by the sensor over an artificially long period of time, with every passing vehicle having its lights tracked and recorded over the visible distance of the road. This causes the lights to appear as a streaked moving line across the image, rather than a fixed point emanating from the cars' headlights.

To take a shot like this one, the following steps need to be taken. First, find a roadside vantage point in which no other moving objects are visible other than the passing vehicles. Second, mount the camera on a tripod, as stability is key while shooting long-exposure imagery. This is because if there is any camera shake while the unit's shutter is open, then the captured light will lose its direction and smudge across the entire image. Next select the shutter priority setting on the DSLR camera and drop the shutter speed to the desired level – for shots like these, this means at least a 30-second exposure. Finally, automatically focus on the scene's background and use an external remote to take the picture.

Interestingly, the very same process is also used in light painting, a technique where the streaked light is controlled by the photographer manually, using light-emitting diodes (LEDs) to draw custom streaks across a dark backdrop and thereby essentially 'painting' in light.

What is it?

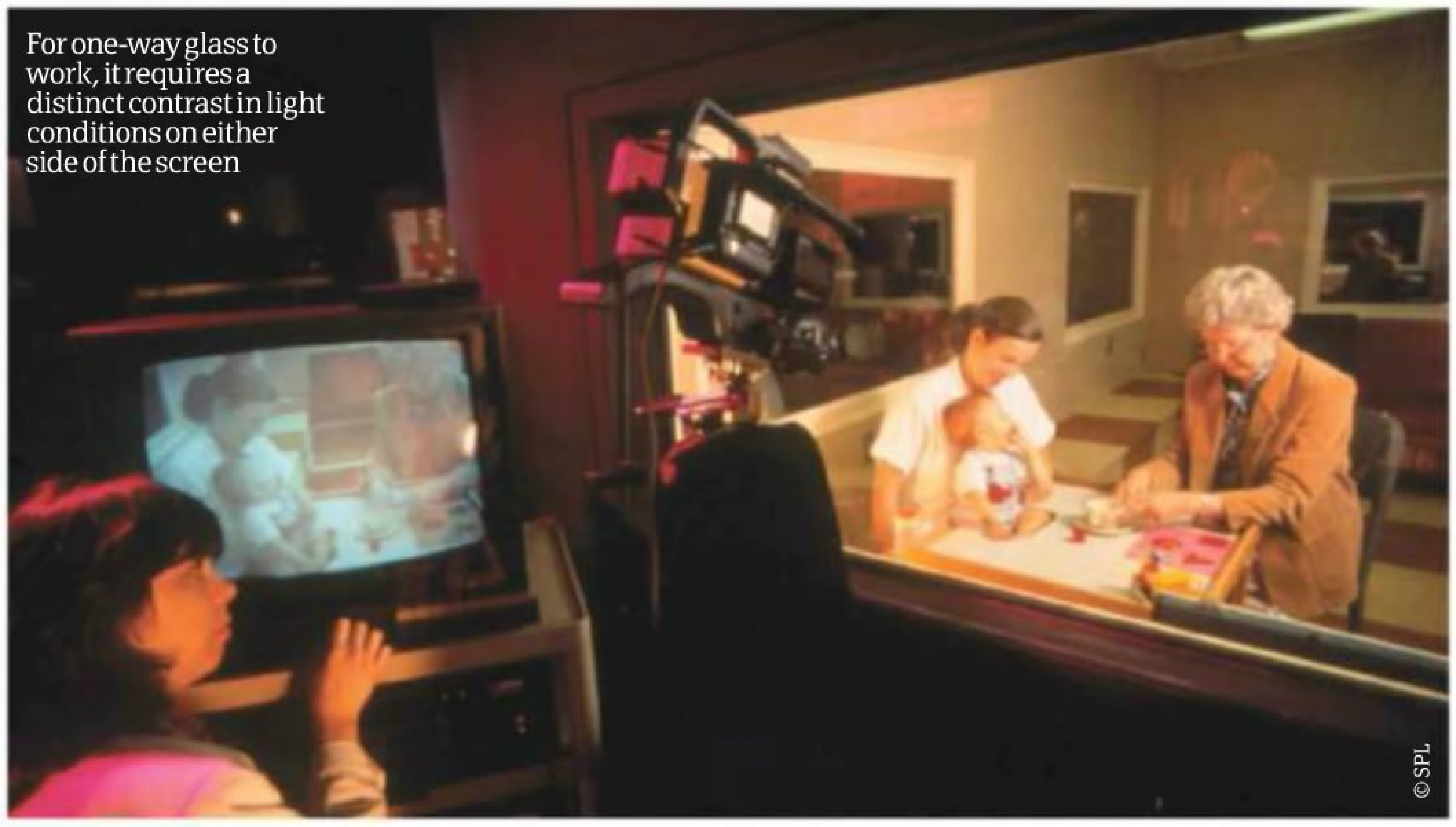
This image shows a long-exposure photograph of a busy road at night. The photographer has achieved this by forcing the camera to use a slow shutter speed when shooting, which has allowed for stationary objects to be captured crisply, but blurs the lights of moving vehicles into colourful streaks.



The trails of light here are all the result of passing vehicles. They follow the direction that the vehicles were travelling while the camera was shooting

What is one-way glass?

What makes one side reflective and the other transparent?


For one-way glass to work, it requires a distinct contrast in light conditions on either side of the screen

© SPL

The secret of one-way glass is that it only works under certain conditions. One side of the glass is covered with a super-thin reflective layer, called a half-silvered coating. It's so thin that about half of all light hitting its surface is reflected while the rest is let through. When placed between two rooms – one that is brightly lit and one that is dark – the mirrored side has plenty of light to reflect, giving it the appearance of a normal mirror.

On the dark side, however, there's enough light allowed through by the half-silvered surface to see the other room perfectly. The effect is ruined if the lights are switched on in the dark room, because the surface isn't opaque so the light, and occupants, can be seen from the other side.

> “The overall effect is ruined if the lights are switched on in the dark room”

How does liquid armour stop bullets?

Why this revolutionary protective gear takes Kevlar to a whole new level

While Kevlar armour offers good stopping power against standard rounds, the material is stiff and heavy. It is battle proven at stopping bullets, but it often does so at the expense of its own structural integrity, warping the armour so it's unusable in the future.

Liquid armour goes a long way to tackling these issues by splicing traditional Kevlar layers with a shear-thickening fluid. The fluid acts as an impact energy displacement layer, hardening upon a bullet's impact and spreading its force out over a larger area than if it were just Kevlar. The fluid turns solid much in the same way that custard does when heated, starting off with a runny consistency, only to become thicker and more dense as it is warmed up.

The liquid's chemical composition, catalysed by the intense heat of the bullet, allows the hardening process to take place instantaneously. Critically, once the round has been stopped, the liquid layer returns to its fluid state, reducing warping and improving the longevity of the kit. Also, the overall thickness of the armour is reduced by nearly half, making the suits more comfortable.

Thinner
The liquid armour is 45 per cent slimmer than standard Kevlar suits.

Stronger
With a third less Kevlar layers, the liquid armour still provides superior stopping power.

Tougher
The liquid armour is also less prone to warping post-impact, extending its life span.

© BAE

What's inside a paintball gun?

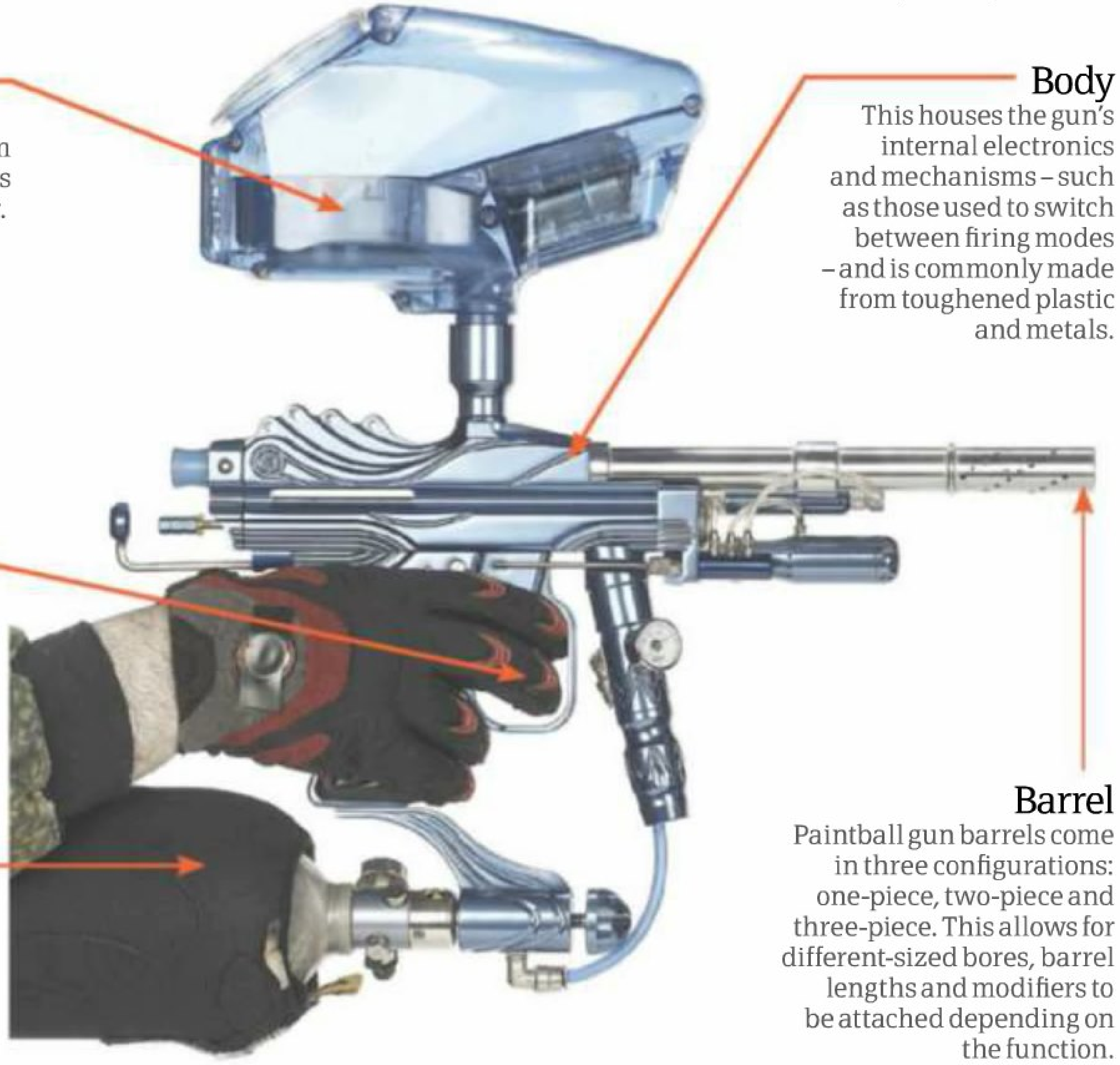
Learn how these recreational weapons and forestry tools fire paint over huge distances

Paintball guns, or markers, can fire gelatine capsules filled with dyed polyethylene glycol at around 320 kilometres (200 miles) per hour. They do this using compressed gas. The gas, once released, pushes upon the paintball at a substantially greater force than the uncompressed air in front of it. Oxygen, nitrogen and carbon dioxide mixes are typically used as the propellant, contained in a pressurised metal canister.

Each gun's barrel can be fed paintballs in a variety of ways, but a hopper is the most common method. When the paintball is released by the hopper, it drops into the barrel in front of a piping system. As soon as the user pulls the trigger – either electronically or mechanically – a valve opens, which releases a burst of the compressed gas. As a result of the gas's natural inclination to equalise with the pressure of the surrounding environment, it drives the only obstacle in its path (that being the paintball) out of the gun at a very high speed.

Paintball gun tech

Examine the key components



Hopper
A plastic container that stores the paintballs. It funnels them into the barrel via a tube that's a single paintball in diameter. High-quality paintball markers can include a force-fed magazine too.

Trigger
When pulled, this injects a small burst of gas into the barrel behind the paintball, shooting it forwards.

Canister
This holds the gas to propel the paintballs. The gas is generally oxygen, carbon dioxide or nitrogen, though some models use propane combustion.

Body
This houses the gun's internal electronics and mechanisms – such as those used to switch between firing modes – and is commonly made from toughened plastic and metals.

Barrel
Paintball gun barrels come in three configurations: one-piece, two-piece and three-piece. This allows for different-sized bores, barrel lengths and modifiers to be attached depending on the function.

How do silencers muffle sound?

How do these special modifiers suppress the bang of a gunshot?

Gun silencers work by suppressing the noise that a weapon makes by slowing the release of expelled gases that are generated by a cartridge post-shot, a process that involves reducing gas pressure.

This is achieved with a series of sound-restraining baffles within the suppressor's long, cylindrical casing, which is fitted to the end of the gun barrel. The baffles are located down the barrel's interior and are angled at 90 degrees to one another at even intervals.

Behind the baffles, at the base of the silencer's casing, is an expansion zone; this allows expelled gases to increase in volume before coming into contact with the baffles. Over the length of the cylinder, this diverts and slows the gases emerging behind the fired round. Typically, applying a silencer to a weapon will drastically reduce the gas's pressure from around 211 kilograms-force per square centimetre (3,000 pounds per square inch) to below seven kilograms-force per square centimetre (100 pounds per square inch). Of course, the centre of the suppressor's cylinder is kept clear to allow the bullet to pass through without obstacle.

Base
A cavity at the base allows gases to expand.

Bullet hole
A bullet-sized gap allows the round to progress as usual.

Baffles
A series of baffles in the suppression cylinder diverts and slows the gases.

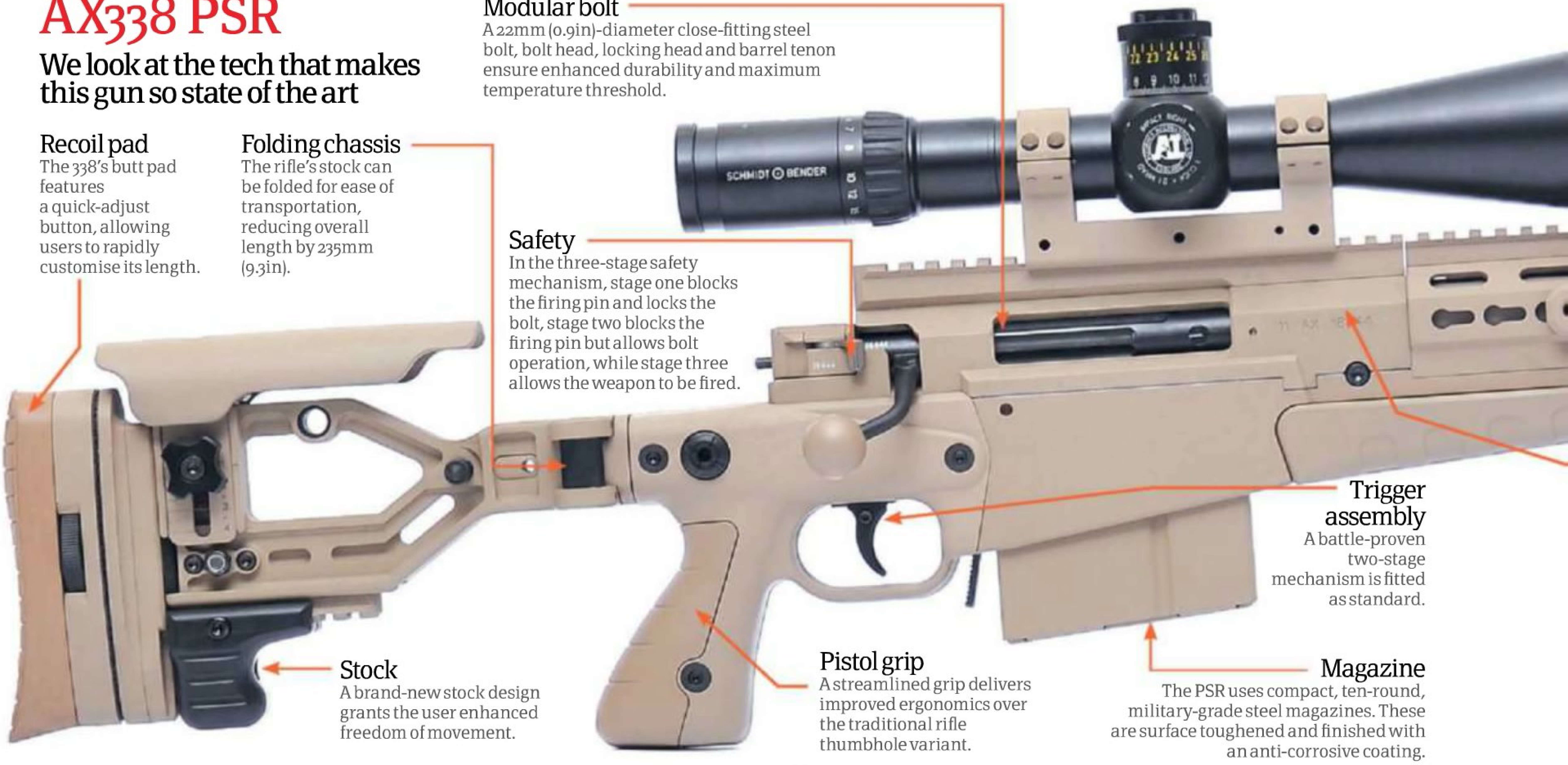
What's inside a sniper rifle?

Accuracy International's AX338 PSR sniper rifle is, arguably, the best long-range rifle in the world. Read on to discover how it is designed and constructed

CAD software is used to complement traditional design techniques

Anatomy of an AX338 PSR

We look at the tech that makes this gun so state of the art



Recoil pad The 338's butt pad features a quick-adjust button, allowing users to rapidly customise its length.

Folding chassis The rifle's stock can be folded for ease of transportation, reducing overall length by 235mm (9.3in).

Modular bolt A 22mm (0.9in)-diameter close-fitting steel bolt, bolt head, locking head and barrel tenon ensure enhanced durability and maximum temperature threshold.

Safety In the three-stage safety mechanism, stage one blocks the firing pin and locks the bolt, stage two blocks the firing pin but allows bolt operation, while stage three allows the weapon to be fired.

Trigger assembly A battle-proven two-stage mechanism is fitted as standard.

Stock A brand-new stock design grants the user enhanced freedom of movement.

Pistol grip A streamlined grip delivers improved ergonomics over the traditional rifle thumbhole variant.

Magazine The PSR uses compact, ten-round, military-grade steel magazines. These are surface toughened and finished with an anti-corrosive coating.

Accuracy International (AI) is unique in its approach to designing any rifle, blending traditional engineering skills and techniques with cutting-edge design and manufacturing technology.

The completion of any rifle begins with user feedback and analysis of any required specification. These can sometimes differ, so finding the optimal balance between the two, as well as between those and the learned experience of the team's designers, is essential.

This process of manual design runs concurrently and in a loop with the weapon's computer-aided design, with first individual components and, eventually, the entire weapon and modifiers designed electronically. The CAD-focused software is an excellent – and relatively recent – addition to AI's production method, enabling the team's head designers to visualise new prototypes much quicker than previously possible.

Of course, a 3D computer model can only take you so far in the creation of any weapon, especially one as refined as a sniper rifle. This is where the first of AI's many advanced machines comes into play. CAD designs for components and entire weapons are then fed into a rapid prototyping machine (RPM), which decodes the CAD drawing and proceeds to lay down physical layers of liquid plastic in a series of cross-sections. These layers gradually build up and, when finished, create a physical version of the CAD schematic ready for handling in the real world. This is a particularly useful tool, as it enables Accuracy International's designers to quickly get their hands on a new item without the huge cost or time penalty of constructing it out of metal.

As soon as a design is finalised, it is parsed down into its requisite parts and tools (quality tools are vital for construction of precision weaponry, as parts need to be constructed identically each and every time) before being sent through for manufacturing at AI's dedicated construction centre.

An AI engineer assembling a new rifle

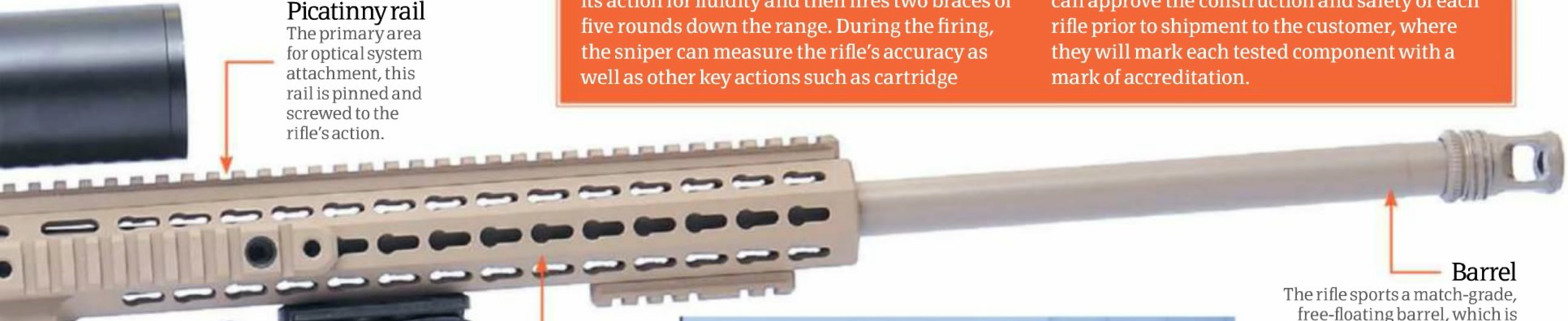
Testing times

AI tests all of its rifles, ensuring safety, reliability and its reputation as a world-class producer of weaponry

All the weapons produced are put to the test at a 100m (328ft) firing range

Upon build completion, each rifle produced by Accuracy International is put through its paces in a dedicated, secure testing facility. This includes a workshop, a 100-metre (328-foot) firing range and, most importantly, an ex-British military sniper. The sniper – who took up the role due to Accuracy International's commitment to improving the tools needed to operate effectively and safely in the field – takes each unit, thoroughly checks it for any defects, tests its action for fluidity and then fires two braces of five rounds down the range. During the firing, the sniper can measure the rifle's accuracy as well as other key actions such as cartridge ejection. Once the sniper is content with the rifle's quality, it is passed through to the armoury. From the armoury, each deposited gun is then examined by an external official in AI's proof house.

The proof house is another dedicated testing room where the governmental representative can approve the construction and safety of each rifle prior to shipment to the customer, where they will mark each tested component with a mark of accreditation.



Picatinny rail
The primary area for optical system attachment, this rail is pinned and screwed to the rifle's action.

Barrel
The rifle sports a match-grade, free-floating barrel, which is threaded deep into the action with a large-diameter thread. Optional barrel lengths, twists and muzzle breaks can be fitted.

Forend rail
Optical, ranging, support and carry attachments can be equipped to the PSR via a free-floating forend system.

Bonded action
The AX338's action is permanently fixed to the aluminium chassis. This eliminates movement, ensuring the sight's accuracy at all times.

One of the most advanced pieces of kit at Accuracy International HQ, a rapid prototyping machine (RPM)

All images © Accuracy International

Taking the AX338 PSR as an example, this process involves the creation of core components such as the rifle's chassis, action, magazines, bolt and firing mechanism, as well as many smaller, though equally as vital, parts such as pins and rails. The elements are created in milling machines, hydraulic presses and spark erosion cutters, each bending, cutting or fining metal into the desired objects. Individual components are removed of rough edges and any debris collected during manufacture through rumblers – large vats filled with smooth stones that rotate and, once parts are dropped in, ensure a smooth and blemish-free finish. When free from imperfections, components are covered with an anti-corrosion coating for extra durability.

After all the rifle's elements have been created the assembly process can begin. Accuracy International has spent a good deal of time maximising the assembly flow of all its rifles, creating a U-shaped assembly line that reduces logistical gaps between the various stages. Importantly, at this point each weapon is partnered with its own identity tag and paperwork, the latter specifying its build stage, bespoke options – such as a folding stock – and final destination.

Finally, as each weapon is completed, it is sent through to AI's dedicated in-house testing facility and proof room. Here, each rifle is tested for mechanical operation as well as component/full-weapon quality. Rifles that meet the exacting standards are then officially stamped and sent to the company's armoury for storage prior to shipment to the required destination.

The statistics…
AX338 PSR

Calibre:
0.338 Lapua Magnum (CIP)

Weight: 7.8kg (17.6lb)

Length: 1,250mm (49in), with up to 686mm (27in) barrel

Action:
One-piece, high-grade steel

Trigger: Two-stage adjustable, set at 1.5-2kg (3.3-4.4lb)

Safety lever:
Three-position safety

Barrel:
Stainless steel match grade, various lengths and twist rates

Chassis material:
Aluminium

Chassis features: Adjustable cheekpiece, rear support leg, sling loops, movable forward accessory rails and sight rail extensions to MIL-STD 1913

Rear support leg:
Height adjustable design with quick and fine adjustment

Carriage:
Four sling attachment points; two adjustable forward mounts

How do fire suits protect people?

How do these space-age-looking clothes shield firefighters from deadly flames?

A fire suit comprises three main layers that, together, keep the firefighter within safe from harm

Fire suits consist of several protective layers of heat-resistant synthetic materials called aramids. These suits must not only protect the wearer from obvious extreme heat and burns, but they must also allow air transfer (to let cool air into the suit and expel body-heated air away), as well as preventing moisture buildup inside the gear itself. There are three main layers to a fire suit: the outer shell, the moisture barrier and, lastly, the thermal layer.

The silver-coloured outer shell seen in these images here must be tough enough to withstand splashes of molten metal, yet flexible enough to enable the wearer to remain mobile. This layer is often a combination of carefully woven fibres made of a fire-resistant variant of Kevlar called NOMEX. A tight weave ensures that the material resists ripping during often strenuous firefighting activity. It also offers a degree of moisture deflection.

Below the outer shell comes an essential moisture barrier, which prevents liquids and chemicals from passing into the suit. This material consists of a breathable fabric such as Breathe-Tex, sewn in with the NOMEX/Kevlar blend.

Third is a strong thermal layer made from Kevlar-based fibres woven into the material. Flames won't penetrate through this layer and it also absorbs around three-quarters of a fire's heat. The temperature of a typical fire ranges from 400-800 degrees Celsius (750-1,470 degrees Fahrenheit).

What's inside a fire sprinkler?

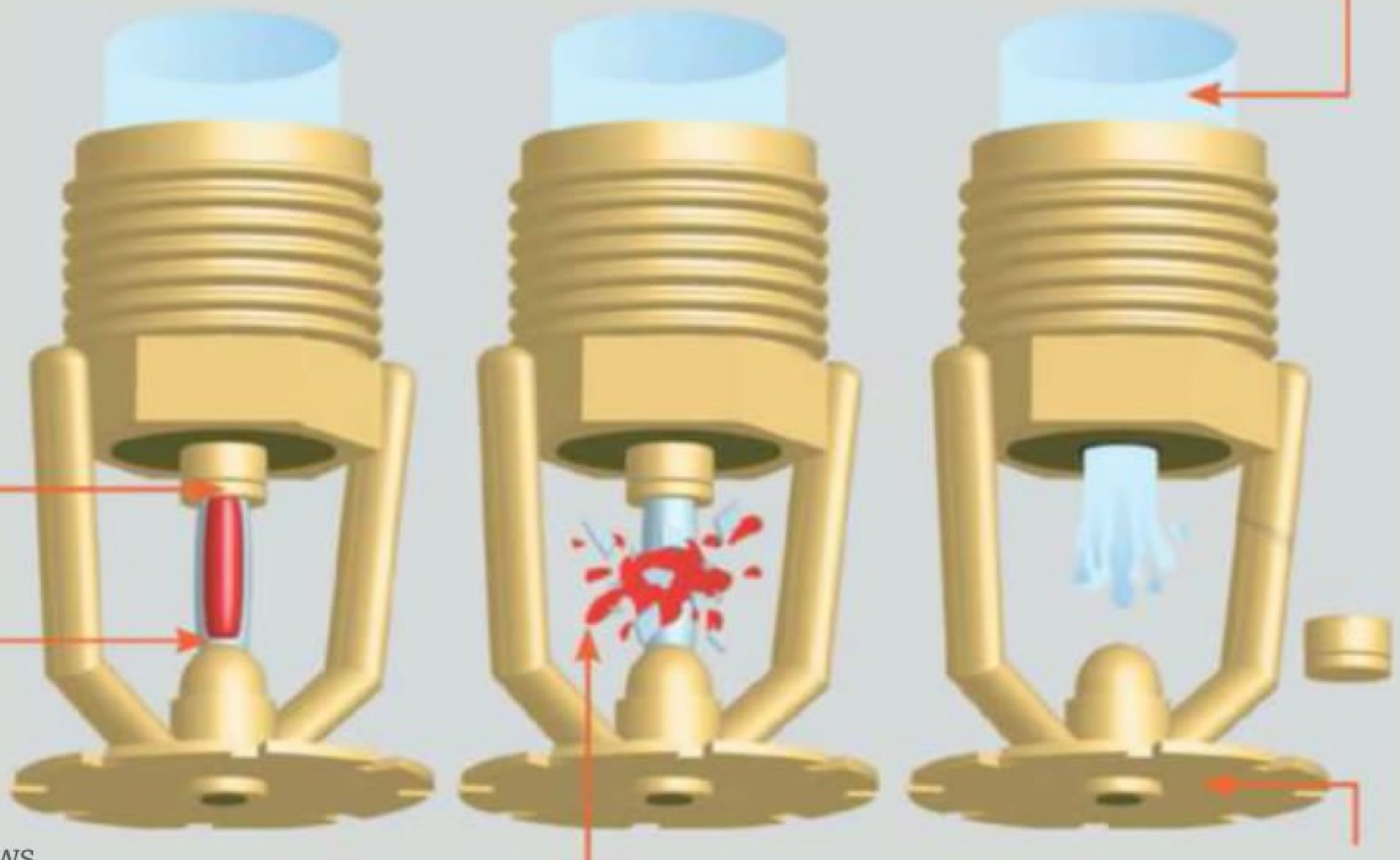
A closer look at how these firefighting devices extinguish a blaze

Fire sprinkler systems are fed by pressurised water from the mains or by their own supply. This water is kept from being released by a plug inside the sprinkler head that will only be released when the temperature exceeds 68 degrees Celsius (155 degrees Fahrenheit). At this temperature, the tiny ampule that seals the plug mechanism will shatter to release a deluge of water.

In more vulnerable environments, smaller-diameter ampules are used for a faster response time. Some sprinkler heads have spring-loaded plates soldered in place over the plug, and are activated when the solder melts. These are known as closed-type sprinklers, because once they are opened, they will spray water until their supply is cut. The on-off sprinkler features a heat-sensitive pilot valve that stops the discharge of water once the temperature has dropped.

Inside the sprinkler head

How does it detect fire and then put it out?



Water supply
The sprinkler head is typically fitted to a network of water pipes and other sprinkler heads that work independently of one another.

Plug
The ampule seals the plug to prevent water being released under normal circumstances.

Bubble
The ampule contains an air bubble that allows for the normal expansion of the glycerin-based liquid inside it.

Ampule
This vacuum-sealed ampule contains a liquid that, when heated, breaks the glass, unsealing the plug to release water into the room below.

Deflector plate
When water is released this plate deflects it downwards in a hemispherical pattern.

Incubators are also called neonatal intensive care units (NICUs)

How do incubators work?

Why do some newborn infants need these protective chambers and what do they do?

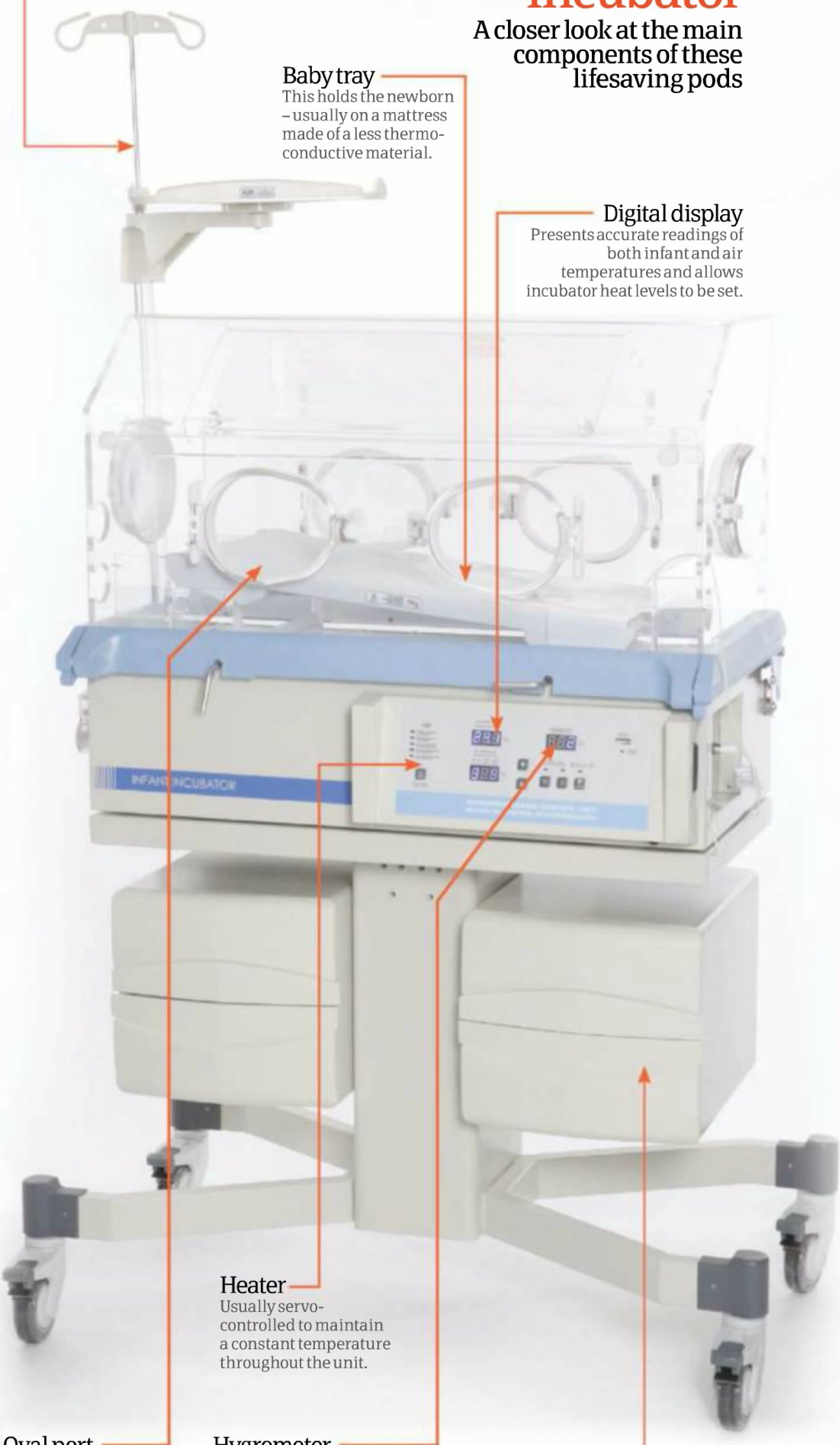
Humans are homeothermic – in other words, we're capable of regulating our own body temperature within a certain range. So too are newborn babies but to a lesser extent. However, some infants – usually those born prematurely – are only able to maintain their body temperature within a very small thermal window. They have poor heat insulation, a relatively large surface area and a small mass, making it very difficult for them to maintain their core body temperature.

The primary task of a neonatal incubator is to maintain an even temperature within an enclosed unit that's designed to eliminate small eddies that can interfere with thermo-neutrality. This is achieved with a bespoke heater and fan, plus a container for water to add humidity to the air and avoid dehydrating the baby. At less than 31 weeks old, premature infants haven't undergone the keratinisation process necessary to protect their skin from drying out, making dehydration and heat loss through evaporation a real danger.

Modern incubators will include a servo-control that will regulate the incubator air temperature using a thermistor, a type of resistor whose resistance varies according to heat; this is attached to the baby's abdomen to monitor body heat. For severely premature neonates (newborns) oxygen may also need to be administered via a nasal cannula tube linked to a control valve within the incubator enclosure.

The neonatal incubator

A closer look at the main components of these lifesaving pods



IV pole
A place to hang any necessary intravenous fluid bags that the infant may require.

Baby tray
This holds the newborn – usually on a mattress made of a less thermo-conductive material.

Digital display
Presents accurate readings of both infant and air temperatures and allows incubator heat levels to be set.

Heater
Usually servo-controlled to maintain a constant temperature throughout the unit.

Oval port
These points provide access to the infant and any equipment inside.

Hygrometer
Measures humidity within the enclosure and displays a precise reading.

Bowl
A receptacle to hold water, used to facilitate humidity in the pod.

A large machine reel of finished paper

What is paper made of?

Explaining the technology and techniques used to create a piece of paper

The base ingredient of the majority of papers is wood, so the first step in paper manufacturing is the harvesting of trees. Once the trees have been felled and shred down to their trunks, they are transported to a paper mill. Once they arrive the trunks are fed through a bark-skimming drum in which they are forced to collide and rub together. This process removes the trunks of all their bark, which while useful in other applications – such as being burned as boiler fuel – is detrimental to creating clean white paper.

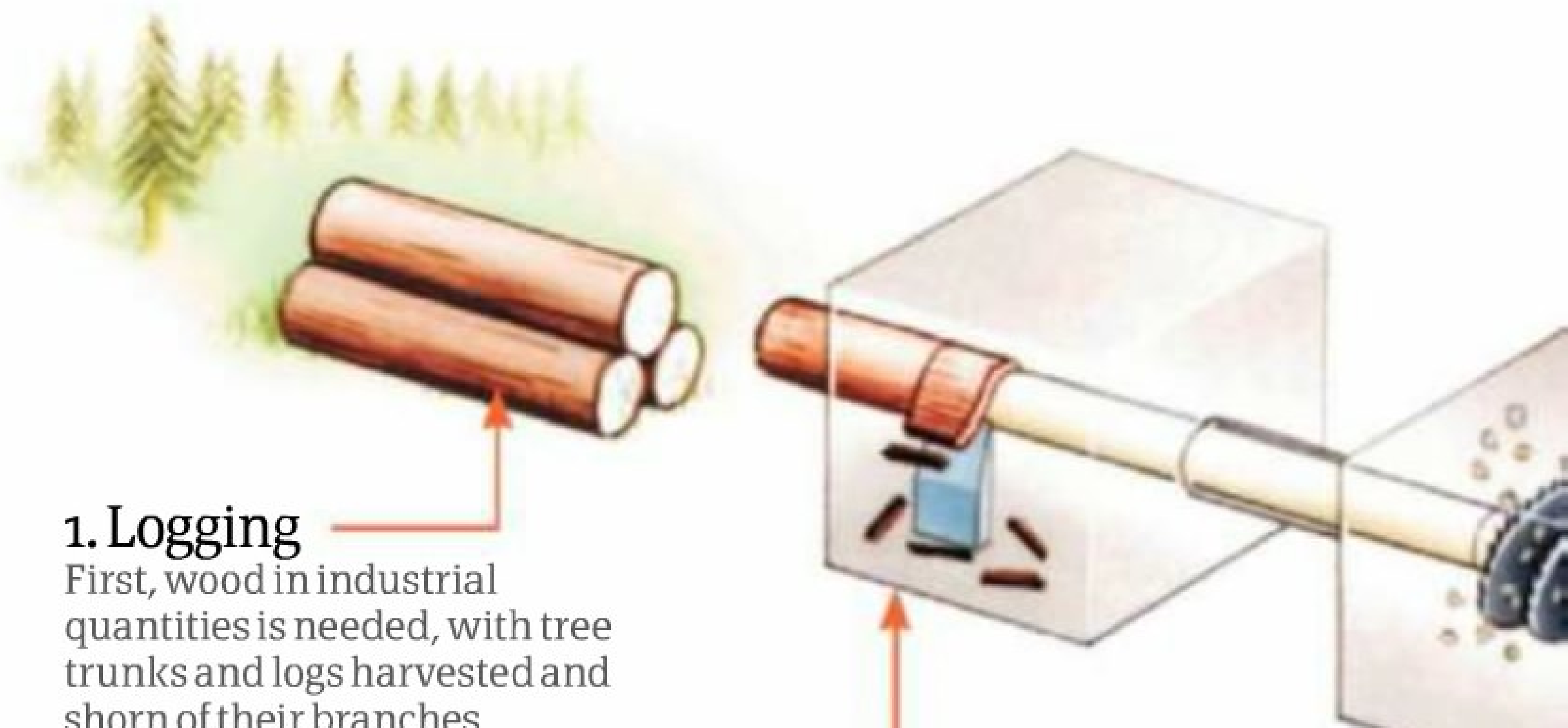
In the next stage of the process, the de-barked logs are sent to a massive chipping unit, which breaks them down into small pieces. The chippings of wood are then fed into large pressure boilers called digesters. These reduce the wood chippings to a gloopy oatmeal-like pulp, which when extracted from the digester rests at a composition of one part fibre to 200 parts water.

The pulp is then deposited onto a high-speed, mesh screen loop, which removes most of the water content and leaves a thin layer of raw paper. This raw paper is pressed and heated in a series of drying cylinders where any remaining traces of moisture are removed. Finally the paper is treated with a starch solution that seals the surface and helps avoid excessive ink absorption during printing.

Historically paper production has transitioned through three main phases, ranging from the manual and bespoke creation of single small sheets from plant and rag fibres, through larger-scale, water-powered paper mills and on to current fully automated and continuous papermaking facilities. Today, many new hardback titles are produced from wood-free paper, which is created exclusively from chemical pulp (a process where the lignin is totally separated from the cellulose fibres during processing) as it is not as prone to yellowing as traditional, wood-based pulp paper.

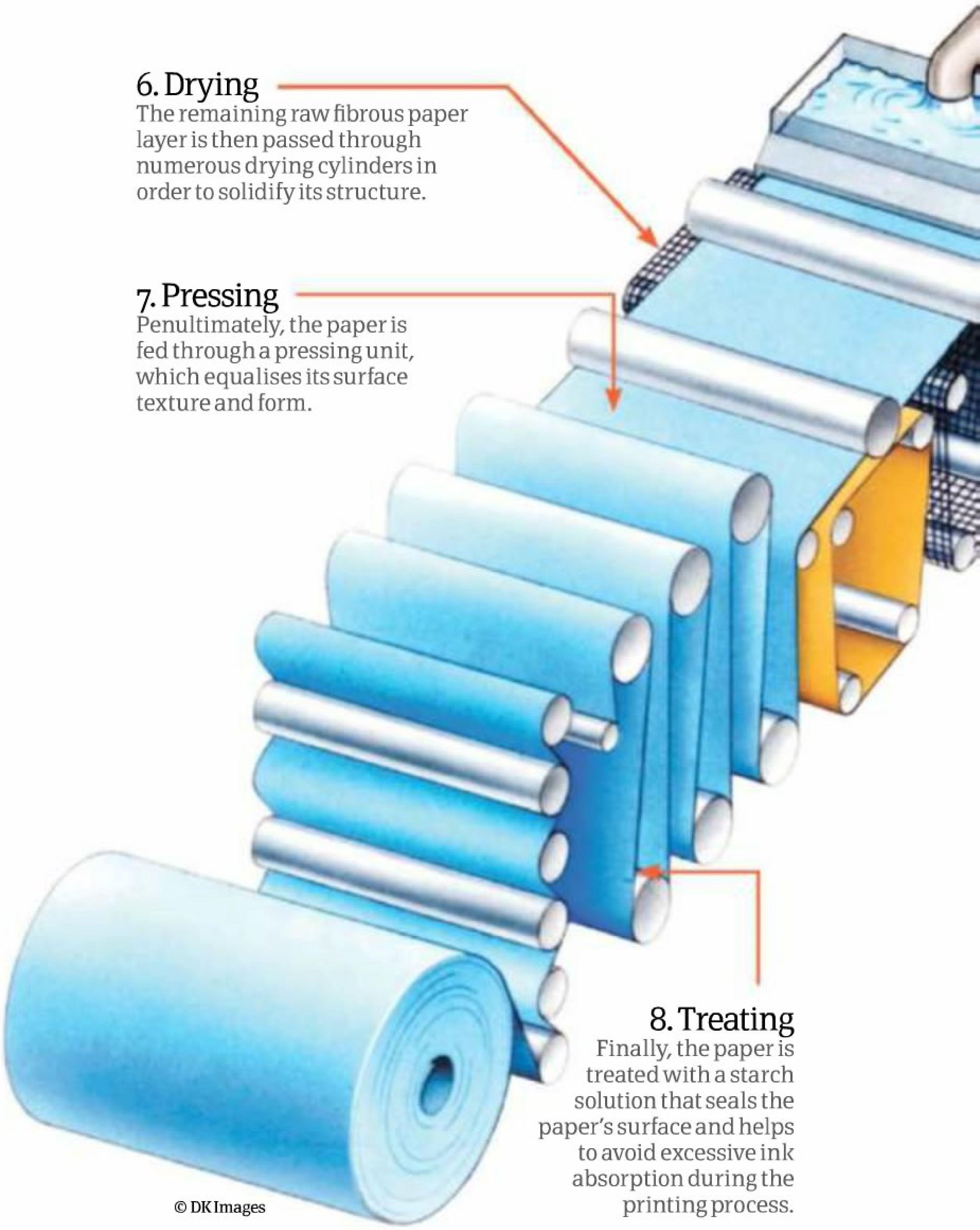
The paper mill production line

From wooden logs to a finished pack of white A4, follow paper manufacturing step by step



1. Logging
First, wood in industrial quantities is needed, with tree trunks and logs harvested and shorn of their branches.

2. Stripping
The trunks/logs are then sent through a stripping machine, which quickly and efficiently removes their bark.

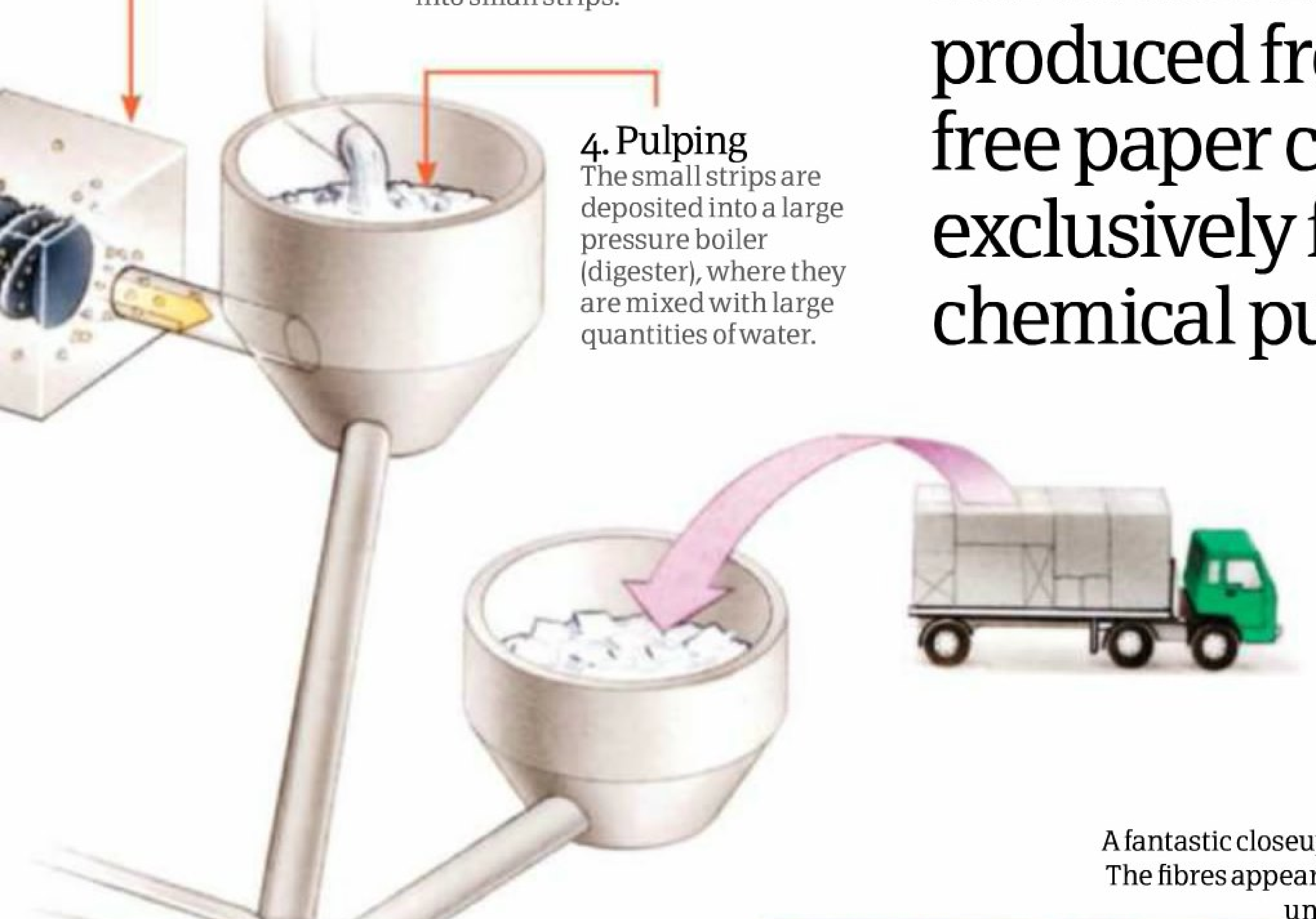


6. Drying
The remaining raw fibrous paper layer is then passed through numerous drying cylinders in order to solidify its structure.

7. Pressing
Penultimately, the paper is fed through a pressing unit, which equalises its surface texture and form.

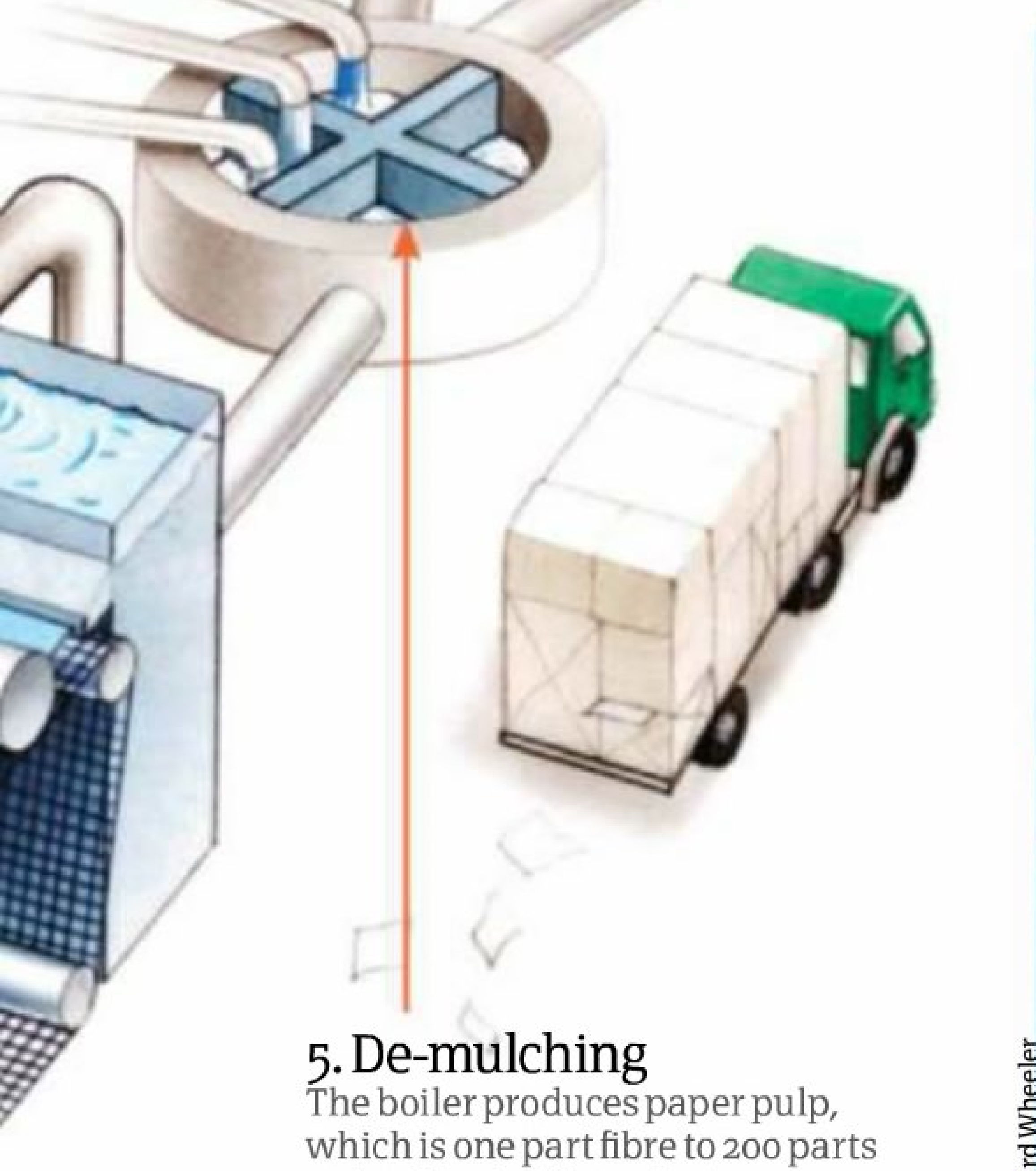
8. Treating
Finally, the paper is treated with a starch solution that seals the paper's surface and helps to avoid excessive ink absorption during the printing process.

© DK Images



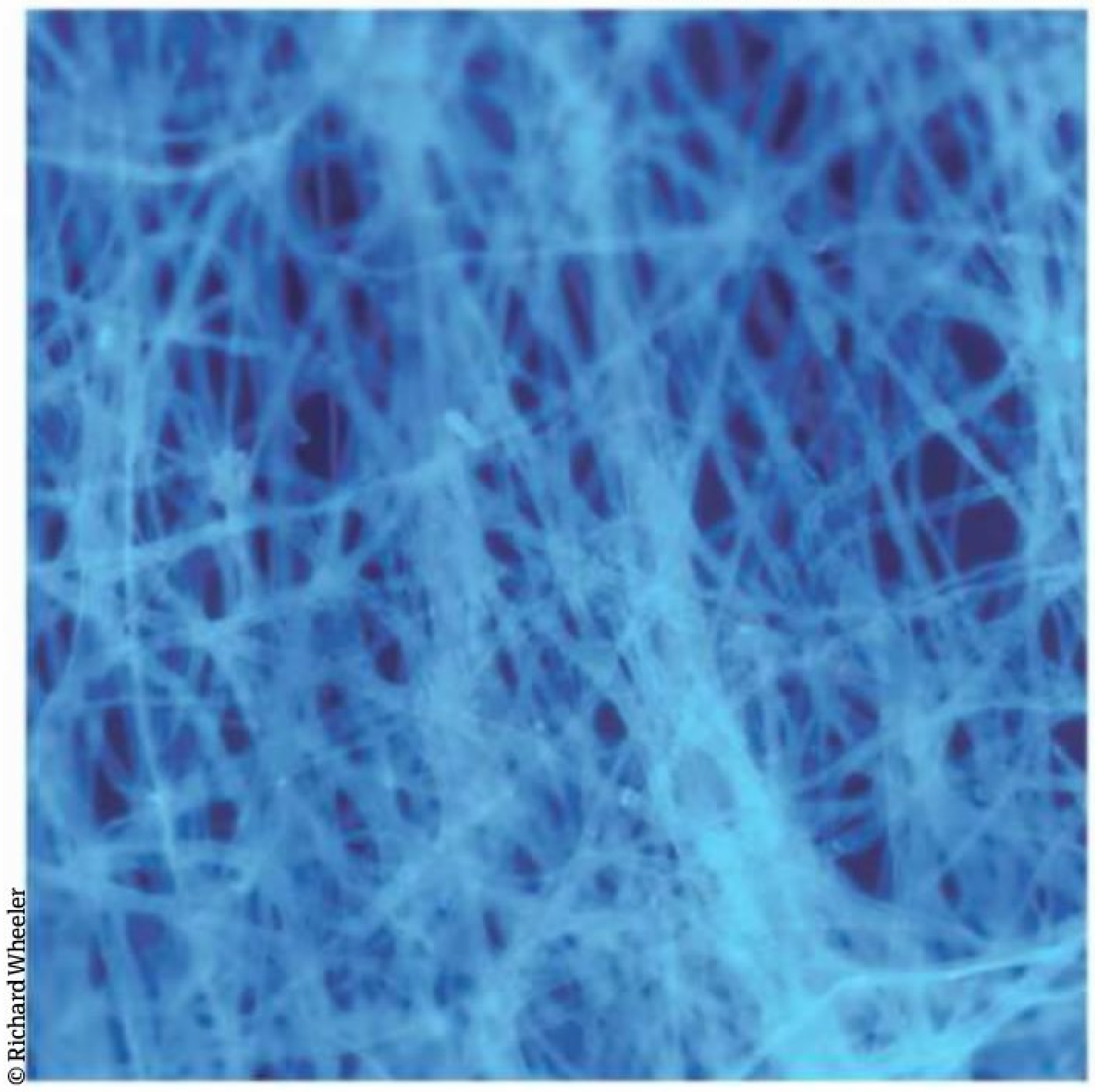
3. Chipping
The de-barked wood is then thrown into a chipping unit, which shreds them down into small strips.

4. Pulping
The small strips are deposited into a large pressure boiler (digester), where they are mixed with large quantities of water.



5. De-mulching
The boiler produces paper pulp, which is one part fibre to 200 parts water. Most of the water is removed via a mesh screen loop.

> "Today, many new hardback titles are produced from wood-free paper created exclusively from chemical pulp"



A fantastic closeup of a sheet of paper's fibres. The fibres appear blue due to autofluorescing under ultraviolet illumination

© Richard Wheeler

Take a peak inside a 19th-Century paper mill

One of the huge rollers which ensures the paper's thickness is uniform

2,000 years of paper

Follow our chronological guide and learn about the evolution and uses of this most versatile manmade material

105 AD

An official attached to China's ruling Han Dynasty creates a single sheet of bespoke paper using mulberry, bast fibres, fishnets and hemp waste.

300 AD

Crude fibrous paper starts to be widely used as a writing medium, with religious officials utilising it for both academic and holy texts.

589 AD

The Chinese begin to use paper as toilet roll.

618 AD

Paper begins to be utilised for other purposes, such as a protective material for wrapping perishable produce, gifts and poisonous substances.

750 AD

Papermaking leaves the Far East and the first water-powered mills are created to produce paper in Samarkand, Persia, along with pump mills.

1220 AD

The papermaking craft diffuses out of the Middle East and into the West, with records showing Italian and later German paper mills appearing. The Gutenberg Bible is created in the 1450s.

1801 AD

Henry Fourdrinier and John Gamble create the Fourdrinier machine, the first continuous papermaking machine in the world.

1844 AD

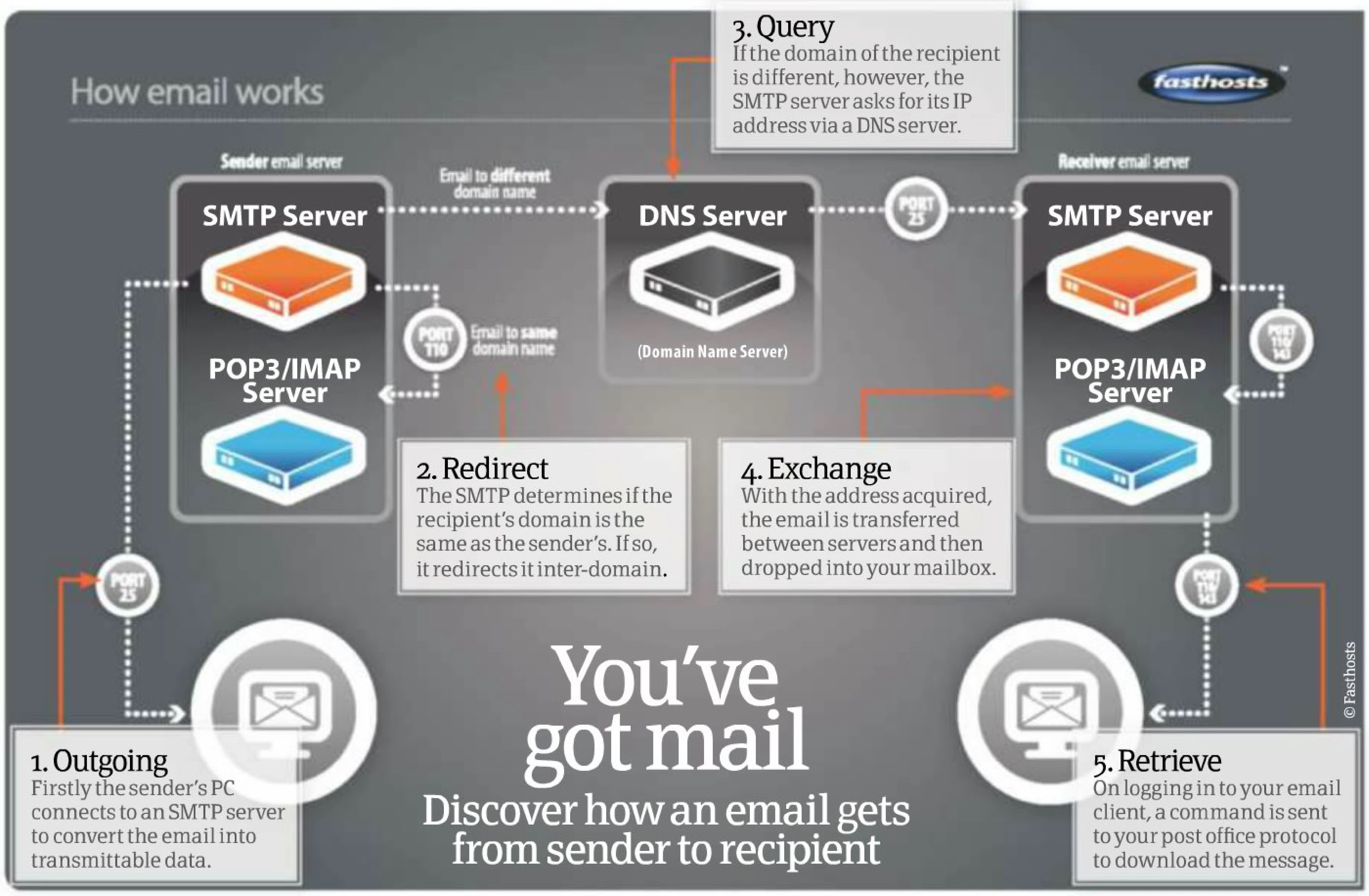
The first wood-pulping machine is invented, enabling paper to be made from wood pulp rather than the more costly rag variety.

1900 AD

The mass-production of paper causes an explosion in produced written texts, leading to the rise and rise of the modern daily newspaper.

2010 AD

Apple releases its iPad tablet computer, initiating a transition from the physical, paper-based document to a digital replica.



3. Query
If the domain of the recipient is different, however, the SMTP server asks for its IP address via a DNS server.

2. Redirect
The SMTP determines if the recipient's domain is the same as the sender's. If so, it redirects it inter-domain.

4. Exchange
With the address acquired, the email is transferred between servers and then dropped into your mailbox.

1. Outgoing
Firstly the sender's PC connects to an SMTP server to convert the email into transmittable data.

5. Retrieve
On logging in to your email client, a command is sent to your post office protocol to download the message.

You've got mail

Discover how an email gets from sender to recipient

© Fasthosts

How do you send and receive emails?

Explaining how an email can cross multiple networks and entire continents in just a few seconds

An email is an electronic text message that is constructed and sent through an email client (such as Microsoft Outlook). Once written, the sending process begins, with the email client connecting to a simple mail transfer protocol (SMTP) server via the internet and through a DSL or line modem. The client then communicates with the SMTP part of your designated email server (for instance, GoogleMail) through a dedicated port.

During the transmission between your email client and server, your email client relays the header information of your email – in particular the recipient's address and the contents within the email body. At this point the SMTP converts the information to a TXT file to send across the web and onwards towards your recipient.

Based on the header information within your email, the SMTP server then contacts the recipient's correct email server. Using the '@' sign as a divider, the SMTP takes the second part of the address to determine the location of the recipient's server. If the domain name is the same as the sender's, the SMTP simply transfers the email information across. If the domain name is different, the SMTP contacts a DNS (domain name system) server and requests the exact IP address for the relating domain name's hosted email server, such as those provided by Fasthosts.

Once the IP address has been obtained, the sender's SMTP server sends out a signal message to the recipient's SMTP over the web and all its gateways informing them that they have received a message. From then, the two servers converse with each other and the email is transferred.

> "The SMTP converts the info to a TXT file to send across the web"

The TXT file converts back into its original form, dropping the message into the bottom of the addressee's mailbox. Finally, when the recipient logs in to their email client, it connects to the internet and commands the recipient's POP3/IMAP (post office protocol/internet message access protocol) server to download all pending messages for viewing on the local machine.

Jargon buster

Break through the complex lingo with our handy guide

Email client: An application used to view, compose and send emails. Examples include Microsoft Outlook, Microsoft Exchange or web-based ones such as www.mail.com.

Email server: A remote machine hosting your email, perhaps sourced from a freemail provider or a web-hosting company such as Fasthosts. The server is split into an SMTP server and a POP3/IMAP server.

Email address: Your unique online site for emailed material that uses a domain name, either individual to you or shared by a company/institution, etc.

DNS (domain name system): A remote server used to convert domain names to IP addresses (unique 32-bit numbers).

SMTP (simple mail transfer protocol): The part of the email server that starts the process for outgoing mail and receiving mail into the correct server.

POP3 (post office protocol)/IMAP (internet message access protocol): These parts of an email server store and download incoming mail for each user account.

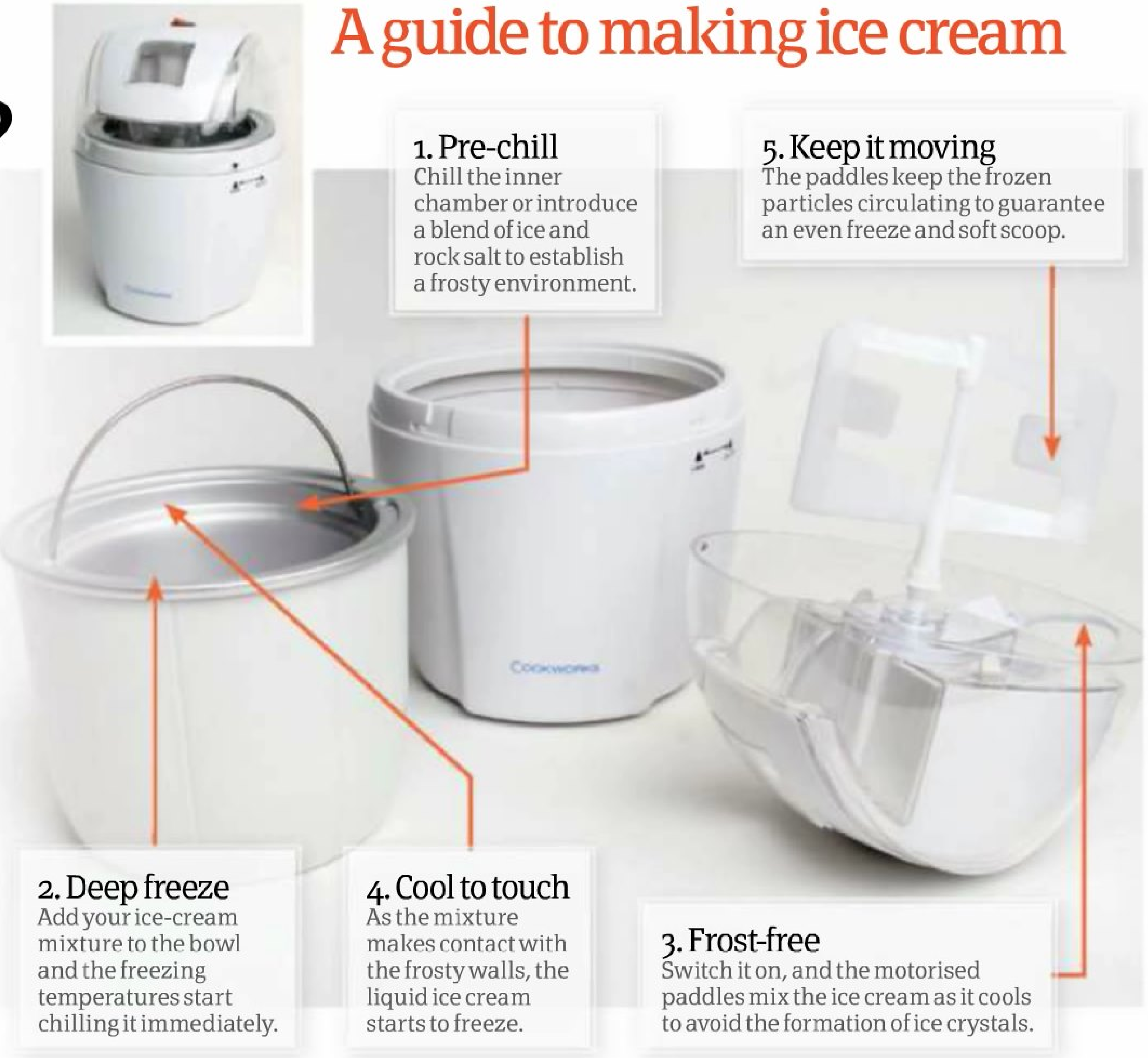
How can you make ice cream?

Inside the machine that transforms ingredients into the much-loved frozen dessert

An ice-cream maker works by simultaneously freezing your ingredients while churning them together. The ice-cream mixture is placed in a double-walled bowl, which has a coolant sandwiched between its two layers. Some more snazzy devices let you remove and pre-chill this chamber before you start, while older versions use a combination of ice and rock salt, which melts the ice to lower its freezing point.

As the ice-cream ingredients make contact with the frozen interior of the bowl, the mixture freezes. A set of paddles driven by a motor continually churns the contents to circulate the frozen particles within the mixture. This motion breaks down any ice crystals that form, while introducing air to encourage a creamy texture recognised as 'soft scoop' ice cream.

If you hanker after a harder scoop, or you're blending a boozy dessert, you may need to refrigerate your ice cream in order to complete the freezing process.



A guide to making ice cream

1. Pre-chill
Chill the inner chamber or introduce a blend of ice and rock salt to establish a frosty environment.

2. Deep freeze
Add your ice-cream mixture to the bowl and the freezing temperatures start chilling it immediately.

3. Frost-free
Switch it on, and the motorised paddles mix the ice cream as it cools to avoid the formation of ice crystals.

4. Cool to touch
As the mixture makes contact with the frosty walls, the liquid ice cream starts to freeze.

5. Keep it moving
The paddles keep the frozen particles circulating to guarantee an even freeze and soft scoop.

What keeps computers cool?

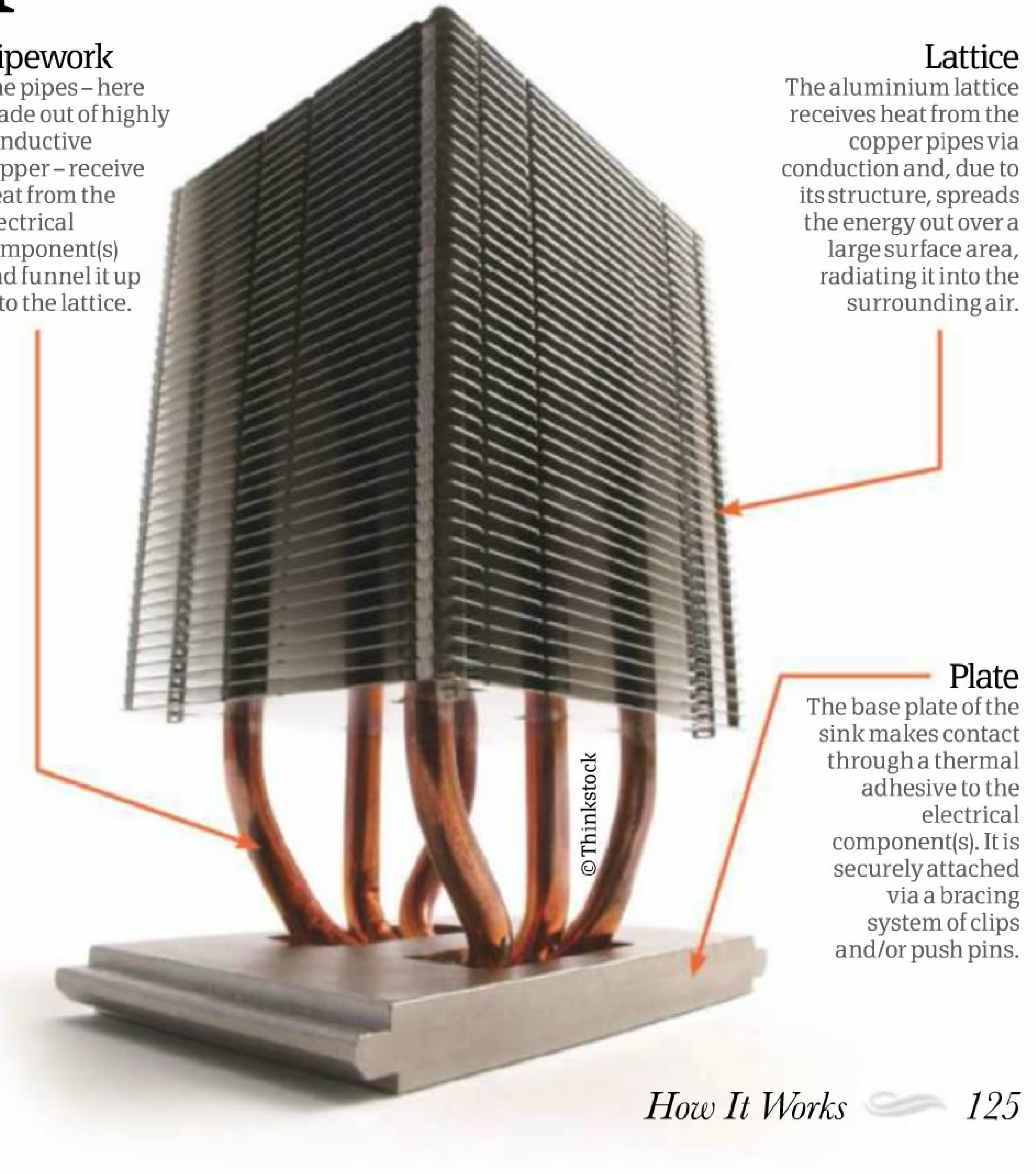
Learn how heat sinks help a computer reach its full potential

Heat sinks are passive cooling components commonly found in computers. They consist of a series of metal plates, pipes, pins and lattices that work together to absorb heat from electrical components through conductivity then dissipate it into the environment.

Conduction, which is the central operating principle of heat sinks, occurs when two objects with different temperatures are placed in contact with each other. When they touch, the hotter object's faster-moving molecules transfer a portion of their energy to the colder object's less-active molecules.

Not surprisingly, for conduction to take place optimally, the two objects must be made out of a material that is a good conductor. Metals, for the most part, are very effective and as such form the base material for almost all heat sink devices. Aluminium alloys and copper are probably the two most commonly used metals on commercial heat sinks.

If we take a computer's central processing unit (CPU) as an example component, its mounted heat sink operates by attaching itself to the CPU's small surface area and then transfers the generated heat away via a series of pipes into a lattice. The lattice allows for a balanced and more rapid radiation of the heat into the surrounding system, which enables the processor to remain at a stable and efficient operating temperature.



Pipework
The pipes – here made out of highly conductive copper – receive heat from the electrical component(s) and funnel it up into the lattice.

Lattice
The aluminium lattice receives heat from the copper pipes via conduction and, due to its structure, spreads the energy out over a large surface area, radiating it into the surrounding air.

Plate
The base plate of the sink makes contact through a thermal adhesive to the electrical component(s). It is securely attached via a bracing system of clips and/or push pins.

© Thinkstock

How do breadmakers work?

Discover how a handy kitchen appliance can speed up the bread-making process

A breadmaker is a semi-automated machine that greatly simplifies a time-consuming process. A typical breadmaker comprises a container with a hinged lid, an internal bread pan, heating element, kneading paddle and circuit board, plus an LCD control panel. The latter offers a range of pre-programmed cycles, each tailored to output a specific product, such as white and whole-wheat loaves.

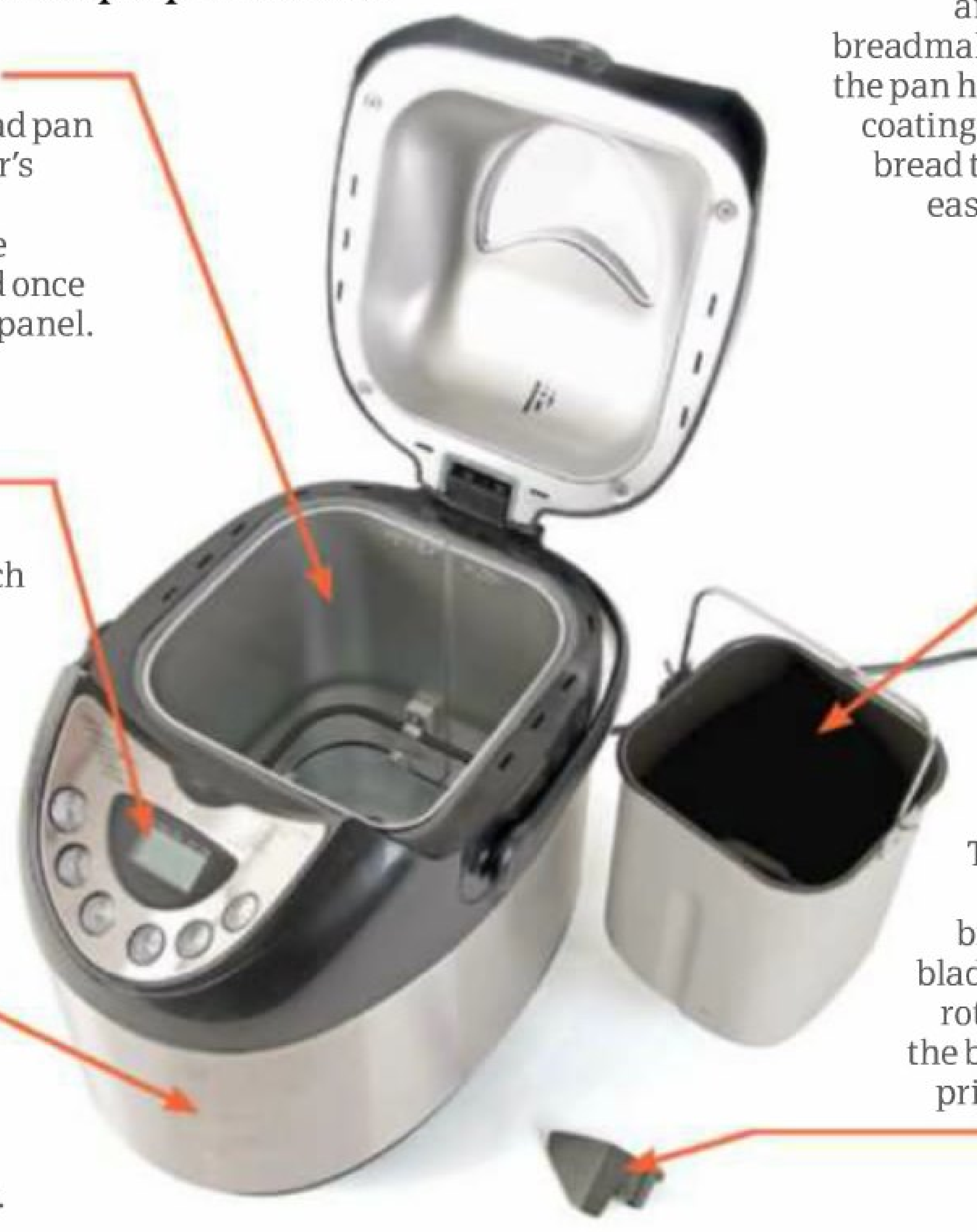
First the user removes the bread pan from the central cavity, before fixing the kneading paddle into the pan's base and depositing the ingredients on top. Now the bread pan returns into its chamber and the lid is closed. The user then selects the desired bread type, baking speed and crust via the LCD control panel and can either start the process immediately, or set it to begin at a specific time.

The ingredients are mixed inside the bread pan by the kneading paddle, while extra items such as yeast, water and flavourings are all added when needed. The dough is then left to rise, in a 'proofing' stage. Once proofed, a heating element activates. The element's temperature is controlled via a sensor on one of the cavity's walls. Baking proper then commences, with the dough generally cooked over 35-50 minutes, followed by a cooling period.

At this point, the machine lets the user know the bread is ready to be removed, usually through a series of bleeps. Due to the pan being covered in a non-stick coating – commonly this will be diamond-fluorine – the finished loaf can simply be dropped out ready for cutting and serving.

Anatomy of an auto-baker

A look at the main features that enable a breadmaker to cook up a perfect loaf



Heating element
At the bottom of the bread pan cavity is the breadmaker's heating element and temperature sensor. The element cooks the bread once activated by the control panel.

Control panel
Various cycles come pre-programmed on each breadmaker, allowing the user to create a variety of breads. These are selected via an LCD control panel.

Electric motor (internal)
Installed within the base of the unit, the motor powers the breadmaker's paddle, typically via a drive belt.

Bread pan
Resembling a metal bucket, the bread pan is both the mixing bowl and oven of the breadmaker. Typically, the pan has a non-stick coating, allowing the bread to be removed easily post-bake.

Paddle array
This sits in the bottom of the bread pan. The blade-like paddle rotates to knead the bread mixture prior to cooking.

What makes tumble dryers dry clothes?

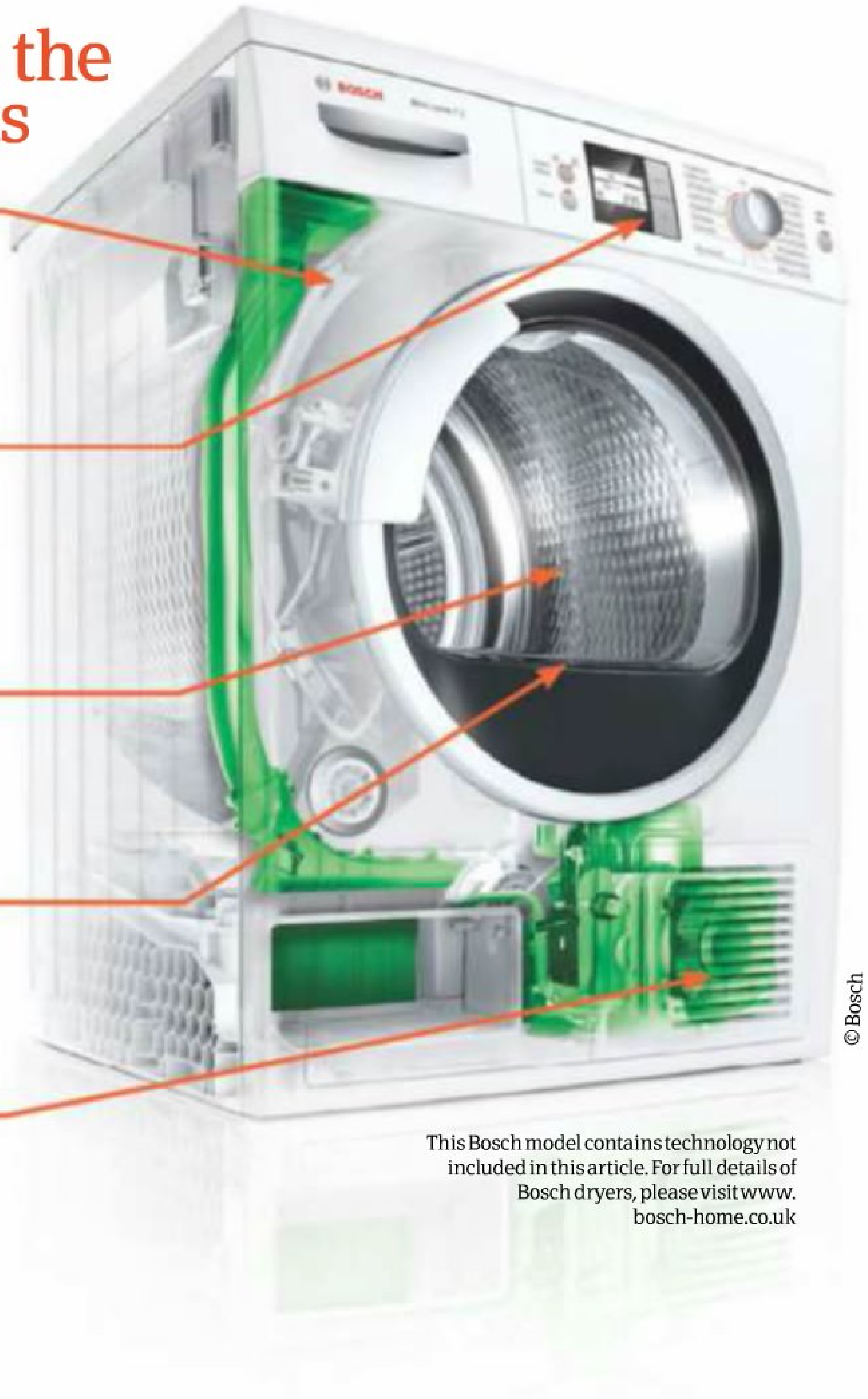
What's the quickest way to dry domestic laundry indoors?

The interior of a clothes dryer consists of a large rotating drum with paddles that lift and separate wet washing as it spins round. This enables the laundry to be efficiently dried by heated air that enters via holes at the back of the drum.

The hot dry air is produced by sucking in cold air that then passes through a heating element. A thermostat sets and regulates the temperature, switching the element on and off to prevent the washing from overheating.

The air exhausted from the drum goes through a filter that traps lint from the dried clothing, and exits through a vent hose. Some tumble dryers send the expelled air through a heat exchanger and condenser to convert it into water that is drained away or collected.

Tumble dryers: the key components



© Bosch

Condensation tray
The moist air is vented out, or goes through a heat exchanger where it is turned into water and drained away or collected in a container.

Control panel
Low and high heat settings and a timer are the simplest controls. Some, like this machine, have many programme settings and a display panel too.

Drum
The stainless steel drum rotates the washing in one direction for several seconds, and then rotates in the opposite direction.

Lint filter
A filter next to the front of the drum collects lint and fluff from the washing; this needs to be regularly cleaned.

Air inlet
Air outside the dryer is sucked in and heated before being sent into the drum.

This Bosch model contains technology not included in this article. For full details of Bosch dryers, please visit www.bosch-home.co.uk

How can ovens cook food?

How different types of cooker provide us with a hot meal

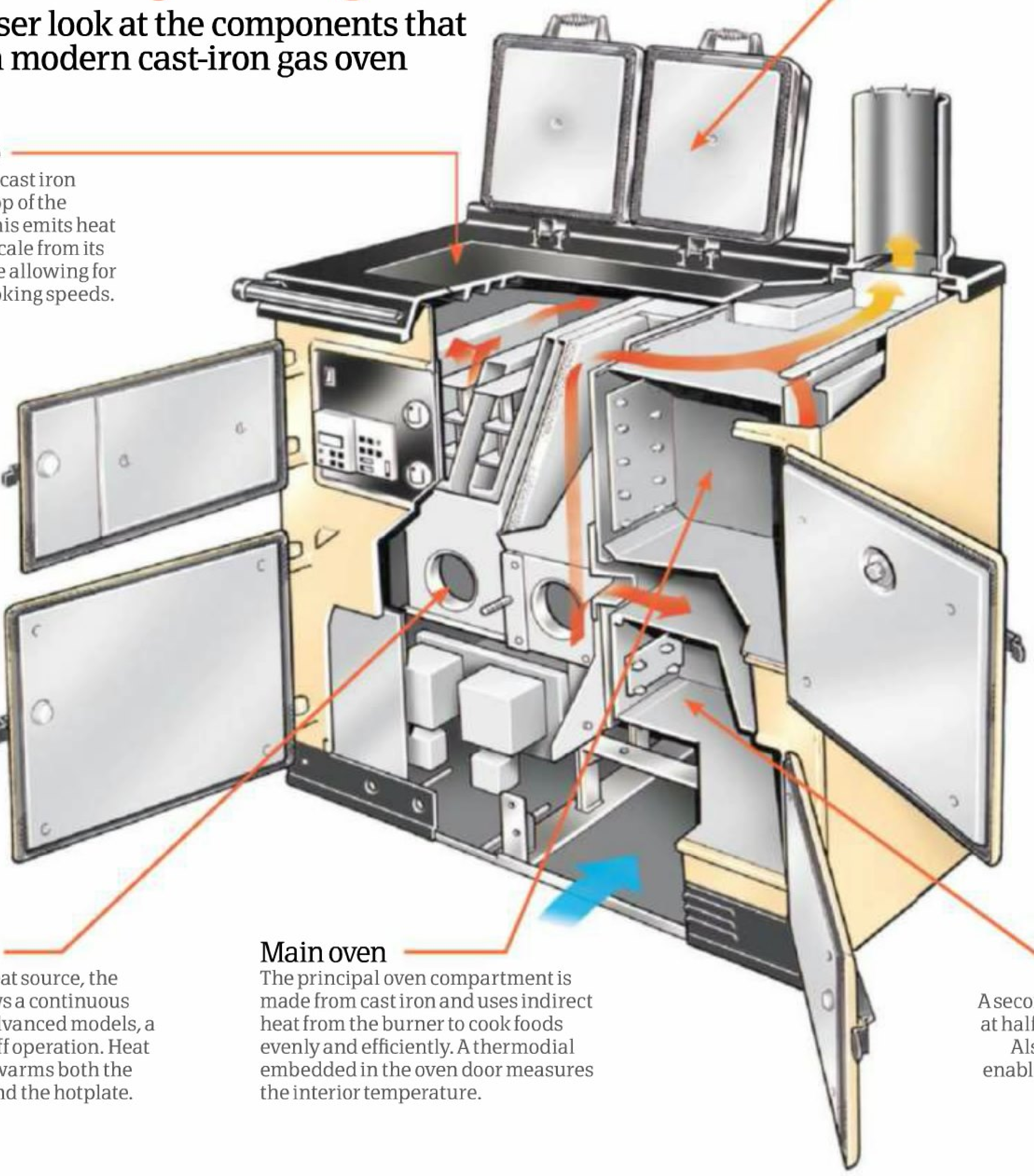
There are two main varieties of household oven – gas and electric – with a few hybrids between the two. The former work by burning gas to warm a heating element and/or a metal cooking compartment directly. The gas supply is ignited using an electric lighter that proceeds through one or more burner units to warm the air in the oven compartment(s) to the temperature designated by the thermostat.

Within the category of gas ovens there are two major types: those that use heating elements – strips of metal in the top and bottom of the oven, and those that heat a metal cooking compartment directly. In both cases, the oven works by emitting thermal radiation, either baking (heated from below) or broiling (heated from above) the food. As a general rule, compartments utilise indirect heat, while elements point heat in a specific direction. Electric ovens also come in two main flavours: standard thermal radiation and convection. Thermal electric ovens work on the same principle as their gas counterparts, with metal elements. Here the energy source is electricity, which passes as a current through the inner, coiled wires of the elements.

Convection ovens are of similar construction to standard thermal radiation cookers but introduce an air-circulating fan into the mix. This fan, which is installed in the rear wall of the oven cavity, aims to distribute the directed radiation from the heating elements around the oven, thereby delivering a more even spread of heat and a faster, more balanced cooking environment as a result.

Inside a Rayburn gas oven

Take a closer look at the components that make up a modern cast-iron gas oven



Insulated lids
When the hotplate is not in use, two large lids can be closed to retain its heat. The lids have an insulated, polished surface allowing them to be handled without oven gloves.

Iron hotplate
A solid one-piece cast iron hotplate sits on top of the oven's chassis. This emits heat on a graduating scale from its sides to the centre allowing for fine control of cooking speeds.

> “The oven works by emitting thermal radiation, either baking or broiling the food”

Burner unit
The Rayburn's heat source, the burner unit allows a continuous gas burn or, on advanced models, a high-power on/off operation. Heat from the burner warms both the compartments and the hotplate.

Main oven
The principal oven compartment is made from cast iron and uses indirect heat from the burner to cook foods evenly and efficiently. A thermodial embedded in the oven door measures the interior temperature.

Lower oven
A secondary oven compartment operates at half the temperature of the main oven. Also made from cast iron, this section enables cooked items to be kept warm or for certain food to be slow-cooked.

© AGA/Rayburn

How do self-service checkouts work?

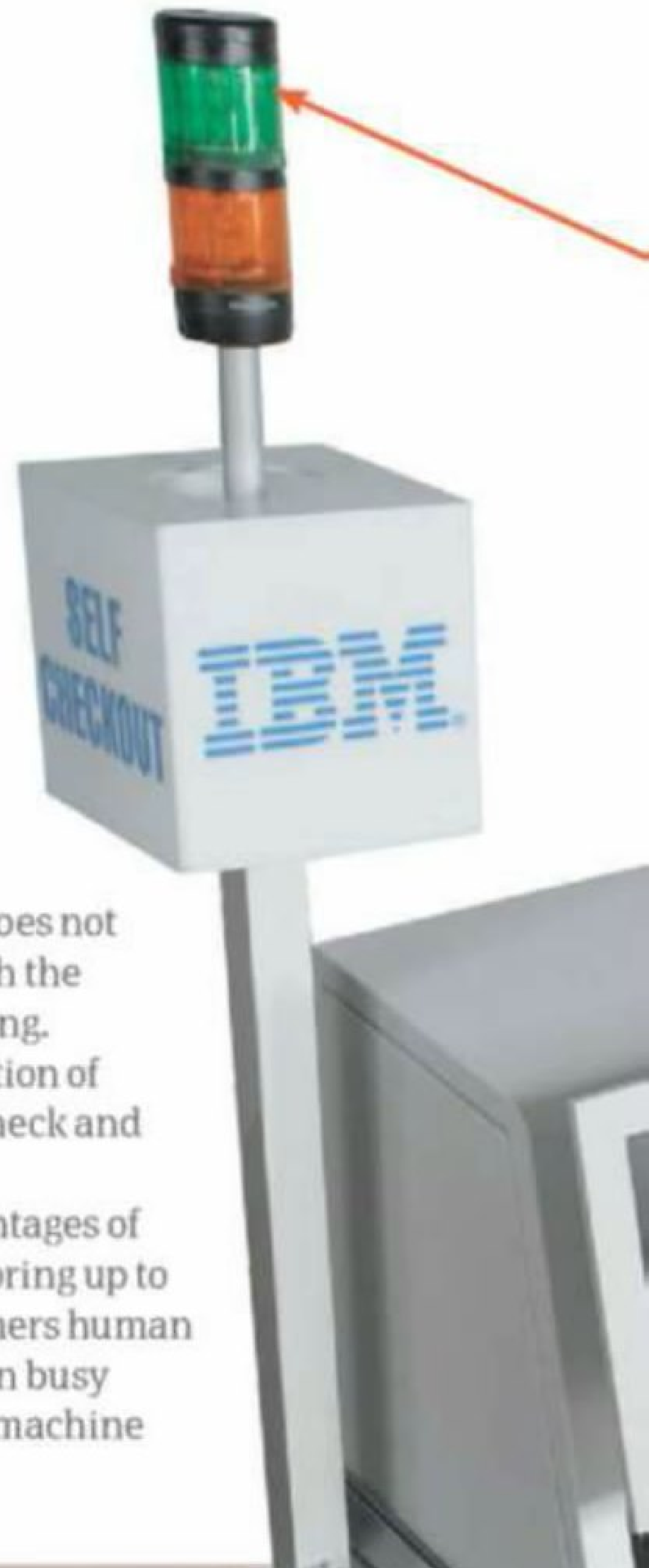
Some people may dislike them but there's no arguing these machines are revolutionising the way we shop

Self-service checkouts have been steadily rising in number since British supermarket giant Tesco introduced the technology in the UK in 2010, with the aim of making paying for groceries much more efficient. From less than 100,000 terminals throughout the world back in 2008 to nearly half a million installed today, they have gone through many changes in this short period, vastly improving in speed and accuracy.

Self-service checkouts come in many shapes and sizes, depending on the floor space available, but usually consist of four main sections: the barcode scanner, touch-screen display, bagging area and the payment terminal. Barcode scanners feature a wipe-friendly surface and see-through panel over which items are passed to be logged. Beneath this panel are components that illuminate, scan, convert and then decode the barcode, swiftly passing data back and forth between the till and its host computer or data centre. Items that can't be barcoded (for example, loose fruit and veg) can be selected manually via a touch-screen display.

Loose items must also be weighed using a pressure pad that matches the item against its expected weight. If this does not happen, the customer and supervisor are both alerted with the now-familiar 'unexpected item in the bagging area' warning. Otherwise, it's simply a matter of paying, using a combination of debit/credit card reader, note reader and coin counter to check and verify the payment.

Despite improvements in accuracy and speed, the advantages of self-checkouts are debated. Certainly, one operator monitoring up to six tills means lower staff costs. However, for some consumers human interaction is a vital part of the shopping experience and, in busy periods, you can end up waiting longer than normal if the machine has a fault.



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Every time you buy a Fairtrade product, you're guaranteeing a better deal for Third World producers
Fairtrade
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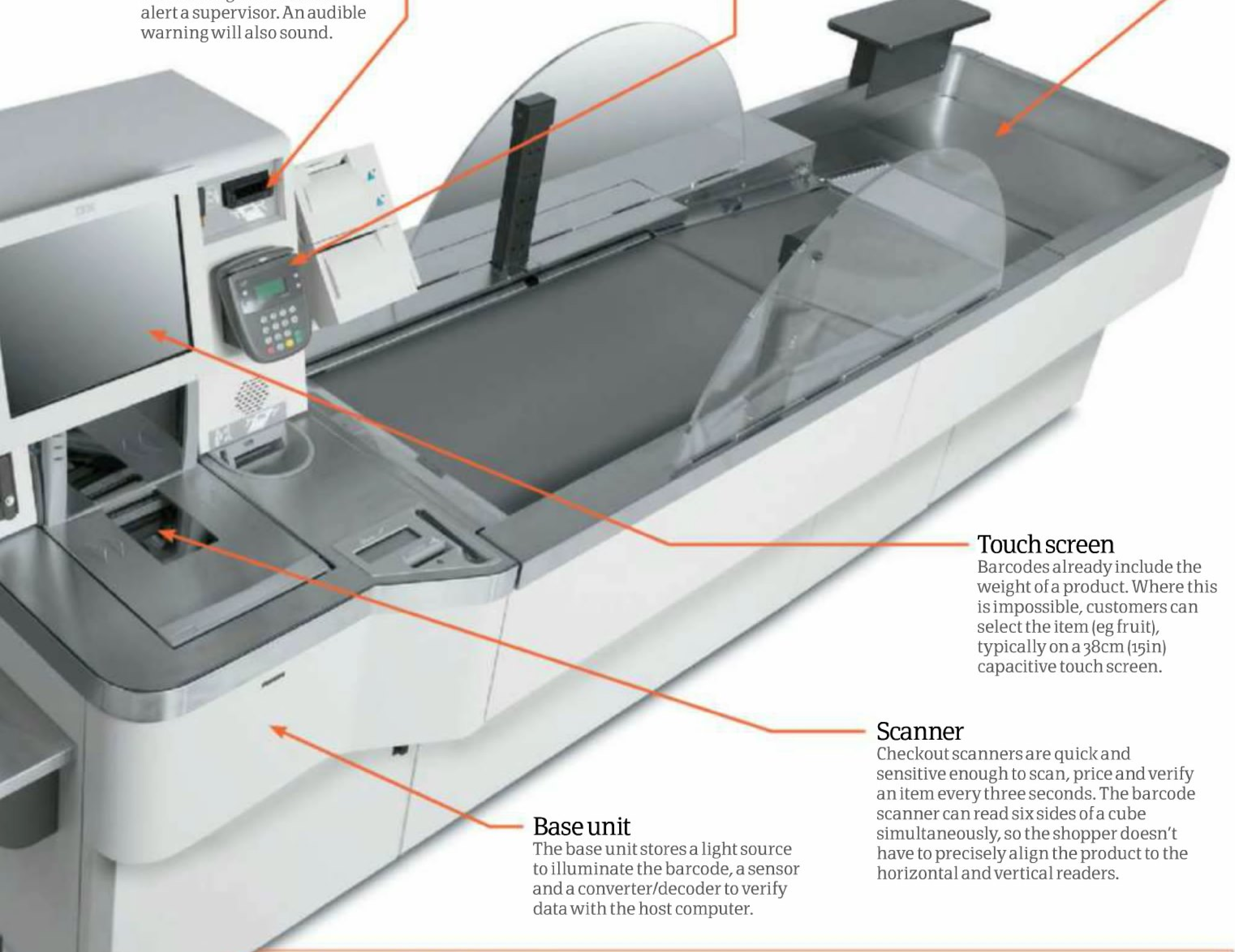
Customer Service
Self Serve Checkouts

Tesco was the first retailer to introduce self-checkouts to the UK high street

The parts of a checkout

We look at some of the key features that make these DIY devices so convenient



Bagging area
A weighing scale linked to a product database verifies the expected weight for each selected item that arrives in the bagging area.

Note reader
Despite their widespread use, note readers are still prone to rejecting notes and coin counters to bouncing change out of the collection tray.

Card reader
Debit/credit card readers are now commonplace and, barring recent network failures, impressively reliable.

Alert system
If a problem is detected, the checkout light will flash to alert a supervisor. An audible warning will also sound.

Touch screen
Barcodes already include the weight of a product. Where this is impossible, customers can select the item (eg fruit), typically on a 38cm (15in) capacitive touch screen.

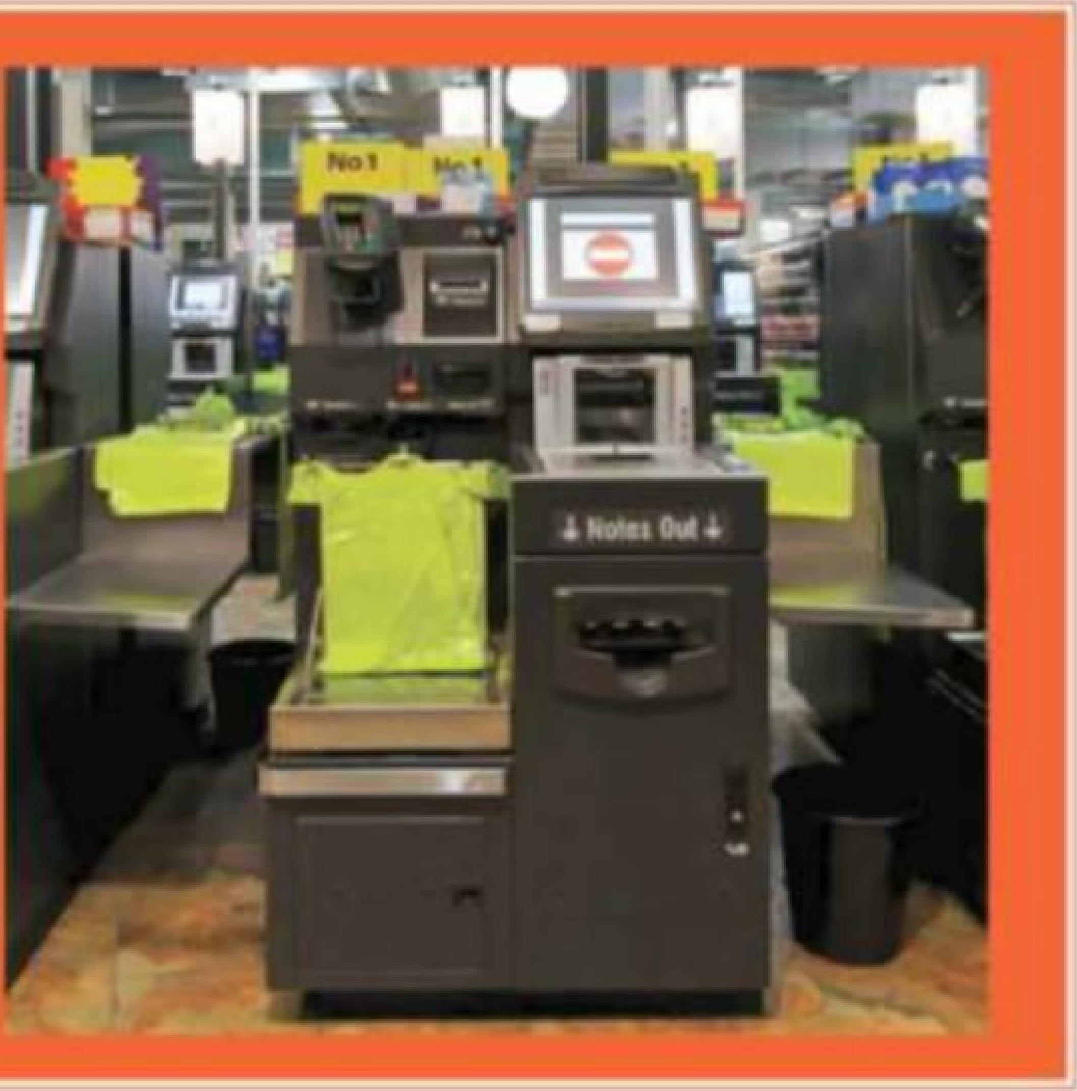
Scanner
Checkout scanners are quick and sensitive enough to scan, price and verify an item every three seconds. The barcode scanner can read six sides of a cube simultaneously, so the shopper doesn't have to precisely align the product to the horizontal and vertical readers.

Base unit
The base unit stores a light source to illuminate the barcode, a sensor and a converter/decoder to verify data with the host computer.

Stand and deliver?

Supermarkets know only too well the threats self-service checkouts pose, not just from committed fraudsters (who have been known to use counterfeit barcode stickers in order to trick the checkout) but otherwise 'honest' customers, tempted by the control they now have over what used to be handled by a real person. However, there are significant security safeguards in each of the key areas of weighing, bagging and paying, as well as constant monitoring by both human and CCTV eyes, in order to prevent theft.

When an error is detected (for instance, an item scanned but not bagged), there are both audible and visual warnings to alert both the customer and supervisor. This also applies to any age-restricted good that need approval. Despite this, research suggests up to a third of all customers have stolen items at self-service tills, using anything from tampering with the scales to bagging without scanning, or simply walking off without paying. Retailers are understandably cagey about revealing exactly how many customers get away with it though.



Barcodes

Barcodes were first developed in the US in the late-Forties, but achieved acceptance with the Universal Product Code (UPC) introduced in 1974 for Wrigley's chewing gum. The UK version (known as UPC-A) consists of a strip of black bars and white spaces above a sequence of 12 numbers, the first six defining the manufacturer, five for the product and a final check digit to ensure the code has been scanned correctly. The bars and spaces are merely a machine-friendly representation of the readable UPC number, designed so it can be illuminated, scanned and checked by the till at high speed.

Once the sale is concluded, barcode data is used in a number of different ways, from controlling stock levels to updating loyalty points and creating a profile of each customer's shopping habits for future marketing. Barcodes have not just made shopping quicker and easier but also helped cement supermarkets' dominance over the last few decades.

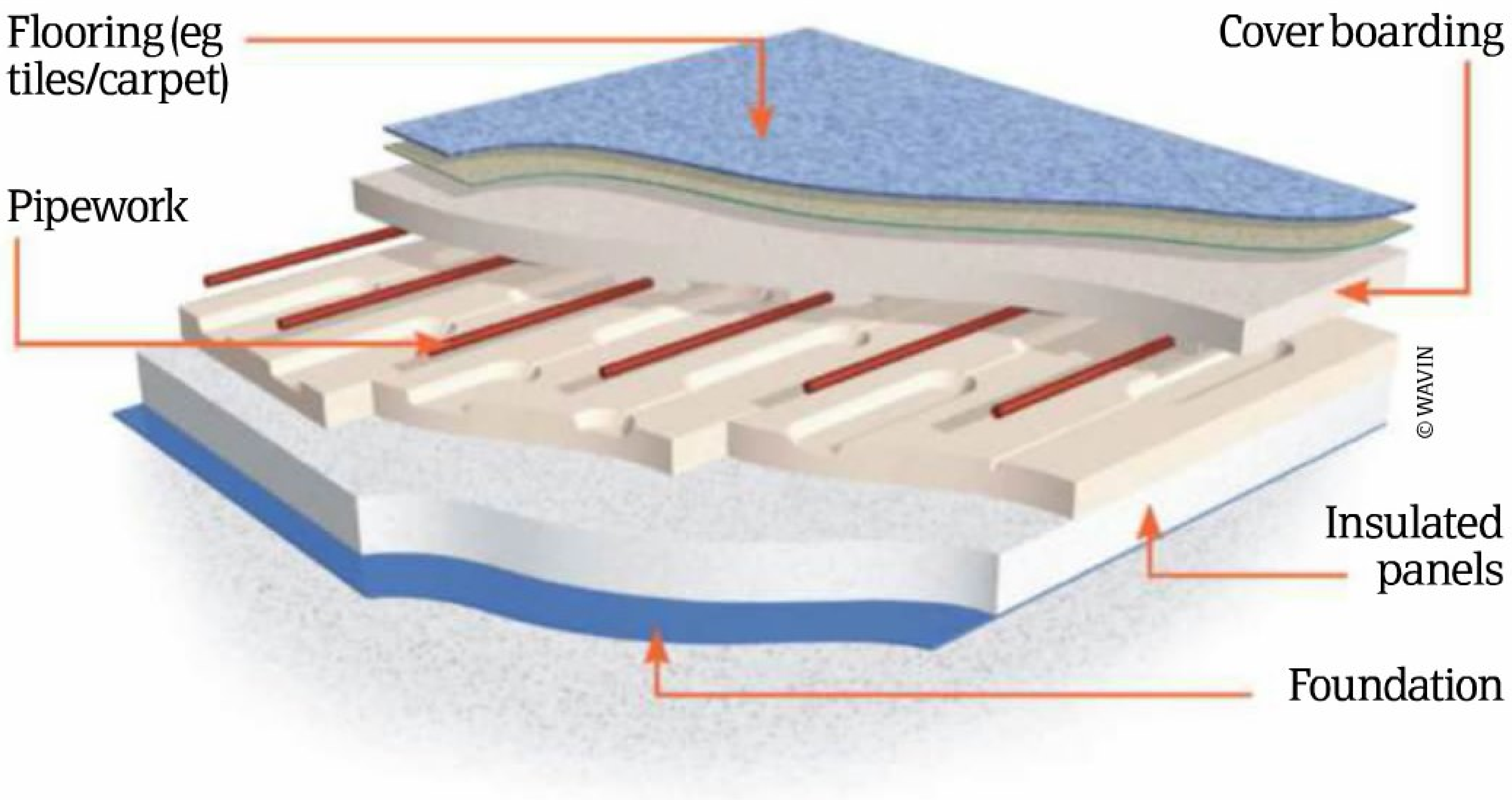
© IBM; Alamy

What is underfloor heating?

What is this economical and efficient way of keeping our homes toasty?

Traditional wall-mounted radiator heating systems convect heat into the room, sending heat towards the ceiling in a circular cycle. In contrast, underfloor heating consists of electric elements, or water pipes, that radiate heat up evenly throughout the whole room. For optimum efficiency, a thermostat in each room can monitor and control the temperature.

Underfloor heating is also unobtrusive and easier to maintain as the elements, or pipework, can be embedded in concrete floors when houses are constructed, or they can be fitted under existing flooring. A saving of 20 per cent can be made on fuel bills, and for buildings with high ceilings, savings can reach as high as 40 per cent compared with traditional heating systems.



© WAVIN

How do saunas stay warm?

The science of these sweat rooms unravelled

A sauna is a small, enclosed room – usually lined with wooden panels – used by people to experience two main kinds of heat session, the goal of both being to induce sweating and the cleansing of the skin. The two main types of heat generated in saunas are dry and wet, which are differentiated by the sauna's humidity level. Dry-heat saunas have very hot temperatures (approaching a blistering 100°C, or 212°F) and very low humidity levels – controlled by an automated system. Wet-heat saunas, on the other hand, have lower temperatures, but higher humidity levels, acting more like a steam bath.

The heat in both cases can be generated in a variety of ways, however the most common practice is to use a stone fire. These are heating elements covered with large smooth stones that, when heated, can have scented water thrown over them to generate large quantities of vapour. These are popular as the heat generated by the stone fire can be spread out more evenly through the water vapour than through standard air convection.

Historically, saunas were pioneered in Finland, where they have become a national tradition. However, the first recorded evidence of a sauna comes from Ancient Greek historian Herodotus, who describes in *Histories* how the inhabitants of Scythia in central Eurasia used to throw water and hemp seeds on heated stones to create a hot, intoxicating steam.

A modern sauna at a health spa with traditional wood-panelled interior

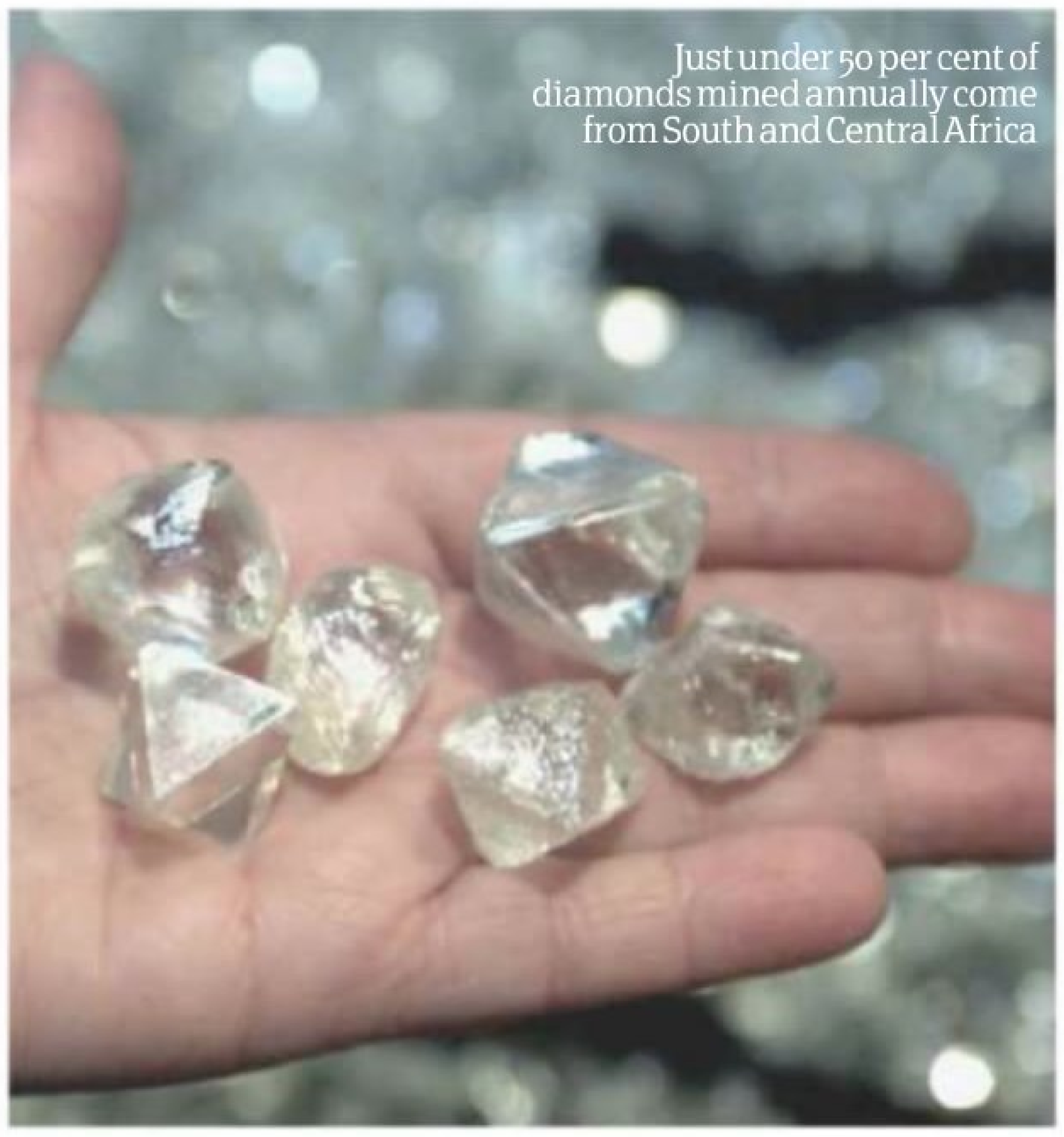
Where are diamonds mined?

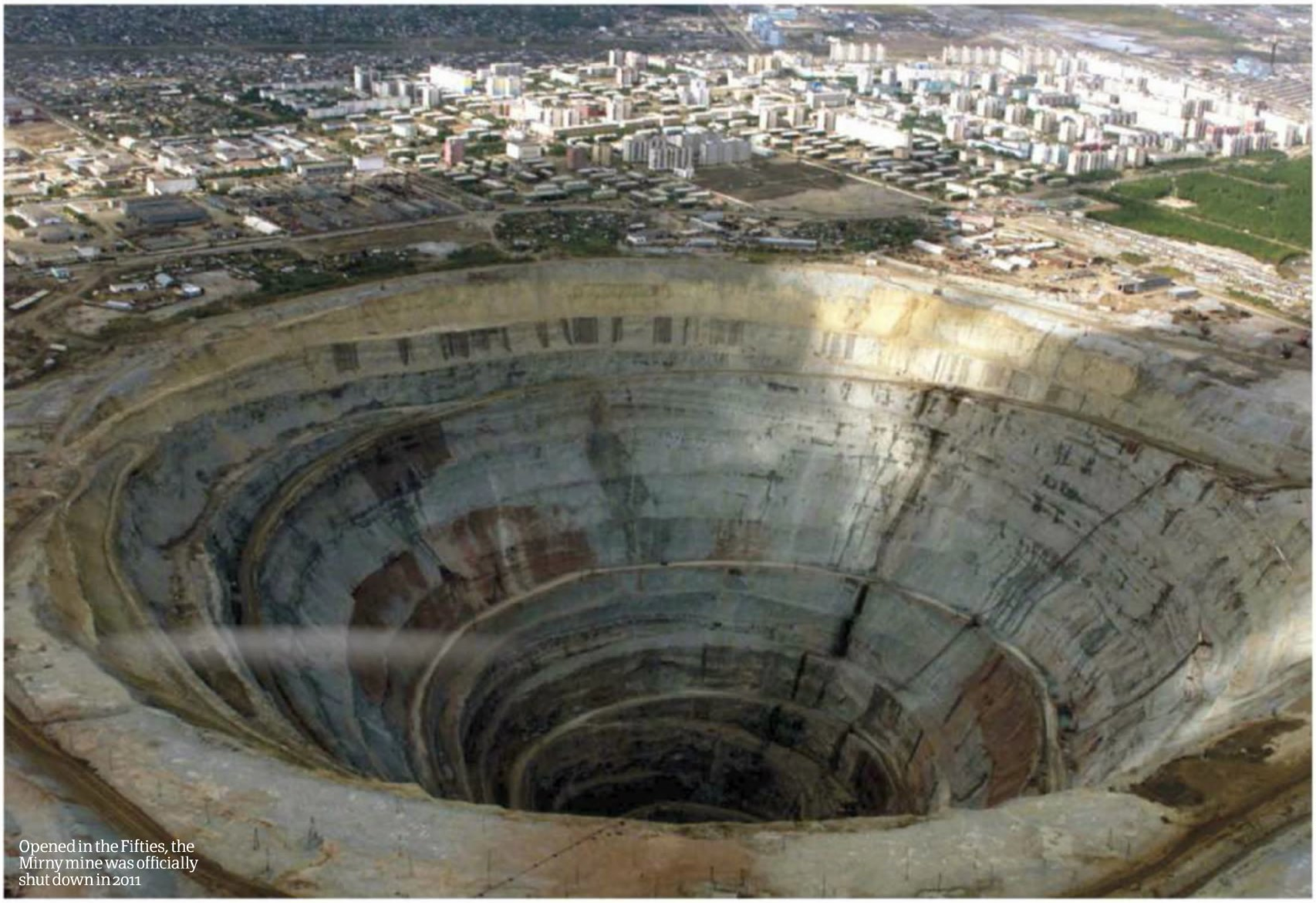
Peer into the second-largest excavated hole in the world in search of treasure…

The Yakutia area of Siberia is one of the coldest and most inhospitable places on Earth. Temperatures of -20 degrees Celsius (-4 degrees Fahrenheit) are common during the winter months. Hardly ideal living conditions but it's here that the town of Mirny sprung up after the discovery of a large kimberlite field in 1955. Why is this igneous rock so important? It's because kimberlite is known to sometimes contain diamond 'pipes'.

The Mirny mine in particular was significant because, up until then, the USSR essentially had no diamond industry. Within a few years this single mine proved such a rich source of diamonds that during the Sixties it was accounting for 10 million carats of the world's diamond industry, which in everyday weight equates to roughly 2,000 kilograms (4,409 pounds) of these precious gems.

Mirny was an open-pit mine up until its last decade of operation. This type of open-cast mining is used when valuable deposits are found close to the surface where tunnelling would be unsafe due to the soft overburden (ie the material above). The mine starts by scraping the topsoil and overburden away to expose the valuable deposits. Mirny was excavated to a depth of over half a kilometre (0.3 miles) in ever-decreasing concentric circles, with the richest diamond-bearing seams found in the upper layers down to around 340 metres (1,115 feet). The open-cast mining method was dispensed with in 2001 and tunnels were dug to retrieve the remaining gems still cost-effective using this method. The Mirny mine was closed in 2011 and the bottom filled with 45 metres (150 feet) of rubble to prevent the pit from collapsing.


Just under 50 per cent of diamonds mined annually come from South and Central Africa


Opened in the Fifties, the Mirny mine was officially shut down in 2011

2x © Reuters/Corbis

How do water turbines work?

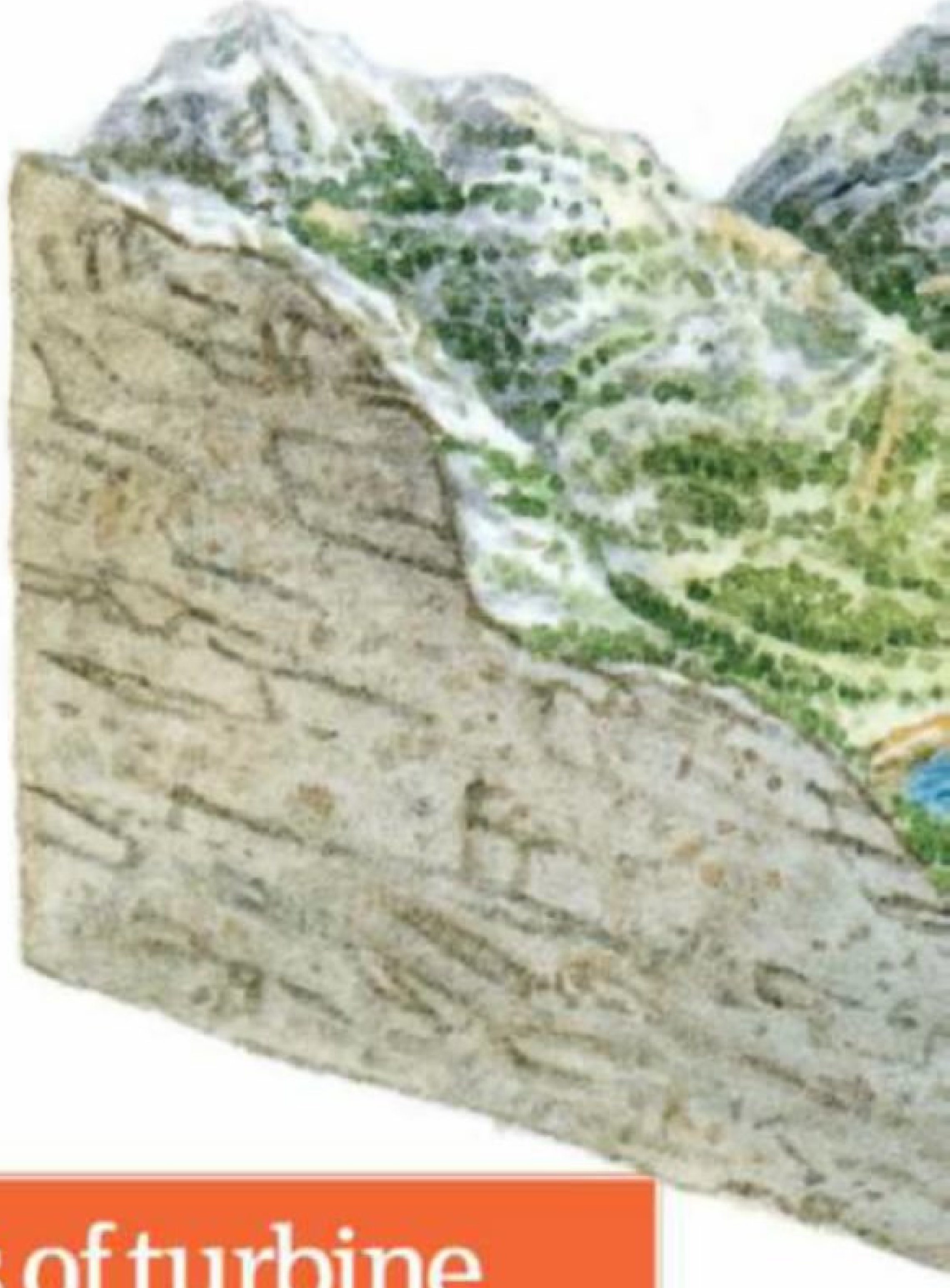
The simple technology that harnesses the immense natural power of water

Water wheels have been around for several thousand years, the concept of using water to power basic machinery like mill wheels (essentially harnessing the Earth's gravity) being well within the grasp of ancient engineers. Turbines are the next natural technological evolution of the water wheel and, although the Romans sometimes used a form of turbine for their water wheels and agricultural uses, it wasn't until the Industrial Revolution (circa 1750-1850) that the first modern turbines emerged.

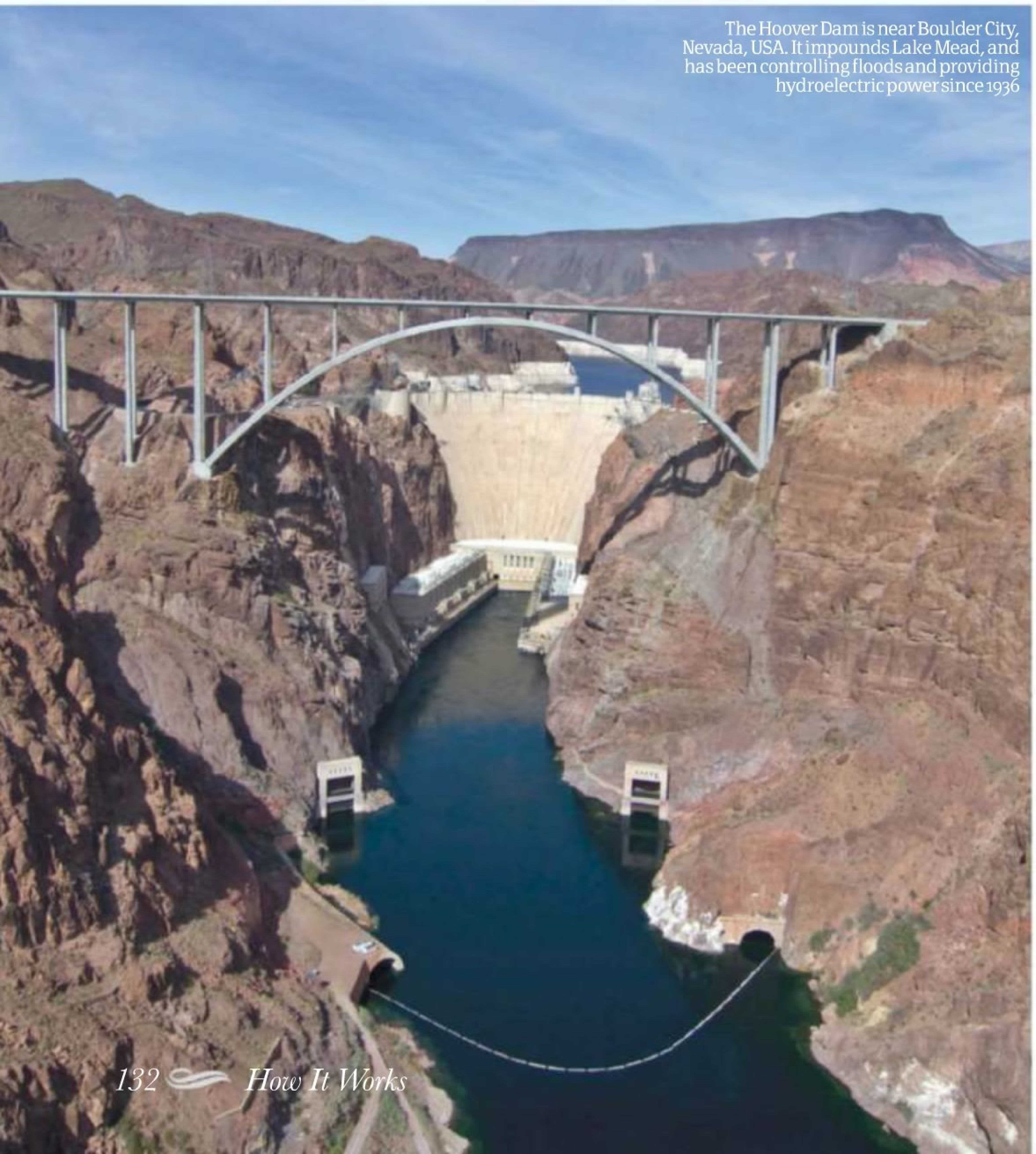
Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law – namely, for every action there has to be an equal and opposite reaction. In propellers, that means energy is put into a spindle of asymmetrical blades that puts pressure on the air or water, which pushes back to propel the vehicle.

Turbines are usually fixed in place, so when a fluid flows through it there is a drop in pressure at the back edge of each blade that causes the turbine to turn. The principle is the same for air or water and the faster the medium is moving, the greater the pressure drop, and the faster the turbine spins. It's a much more efficient method than water wheels that yields greater hydraulic head (ie the amount of force the water can generate) with smaller apparatus.

Historically turbines directly drove the huge factories of the 19th Century, but since the dawn of electricity, they're used to generate power that can be stored or passed on to the national electrical grid for a clean and renewable source of power.



Source
Whether a lake or river, the source of water is chosen for its elevated position, from which the dam can take advantage of gravity.



The Hoover Dam is near Boulder City, Nevada, USA. It impounds Lake Mead, and has been controlling floods and providing hydroelectric power since 1936

© Alamy

Types of turbine

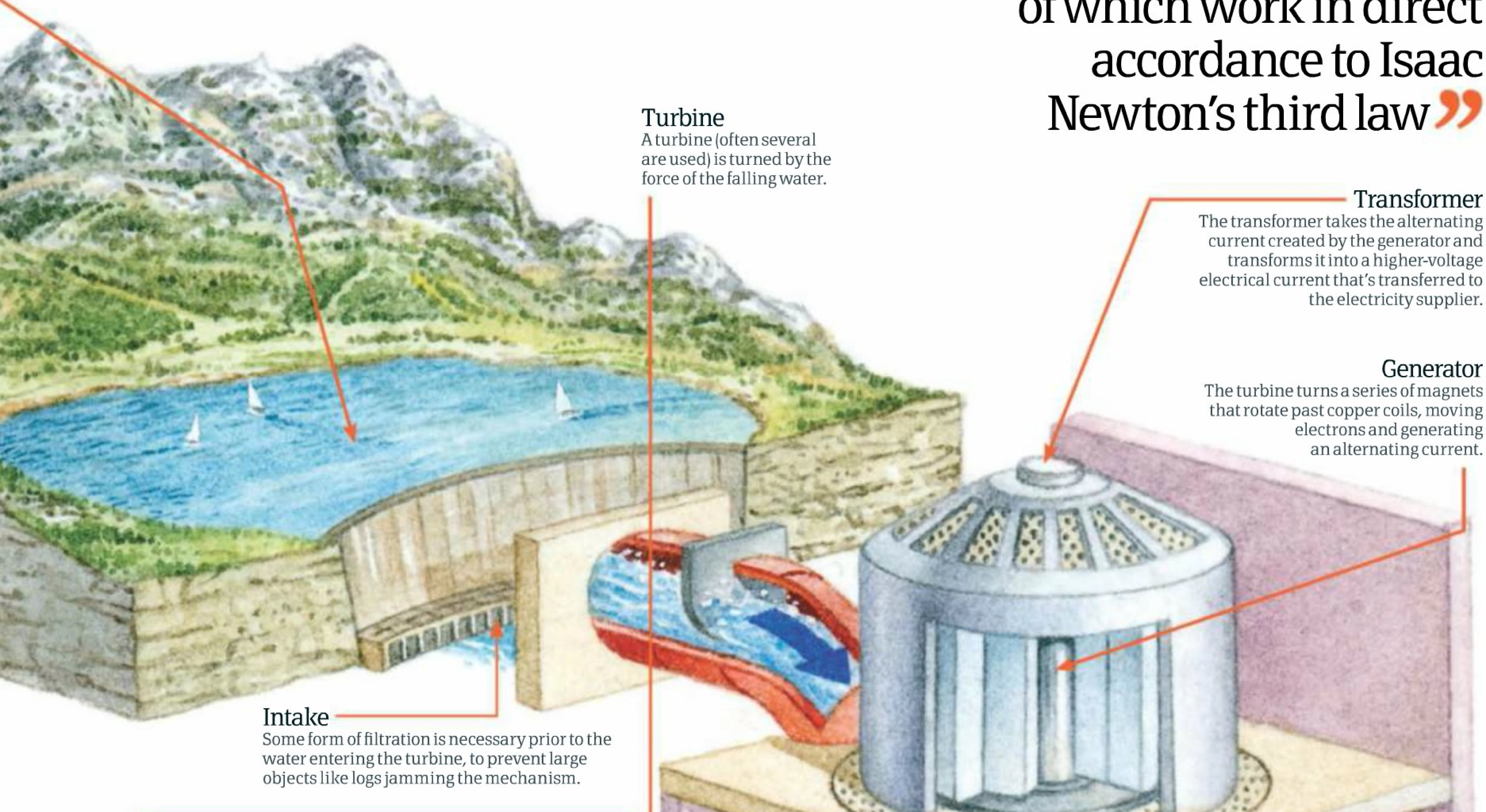
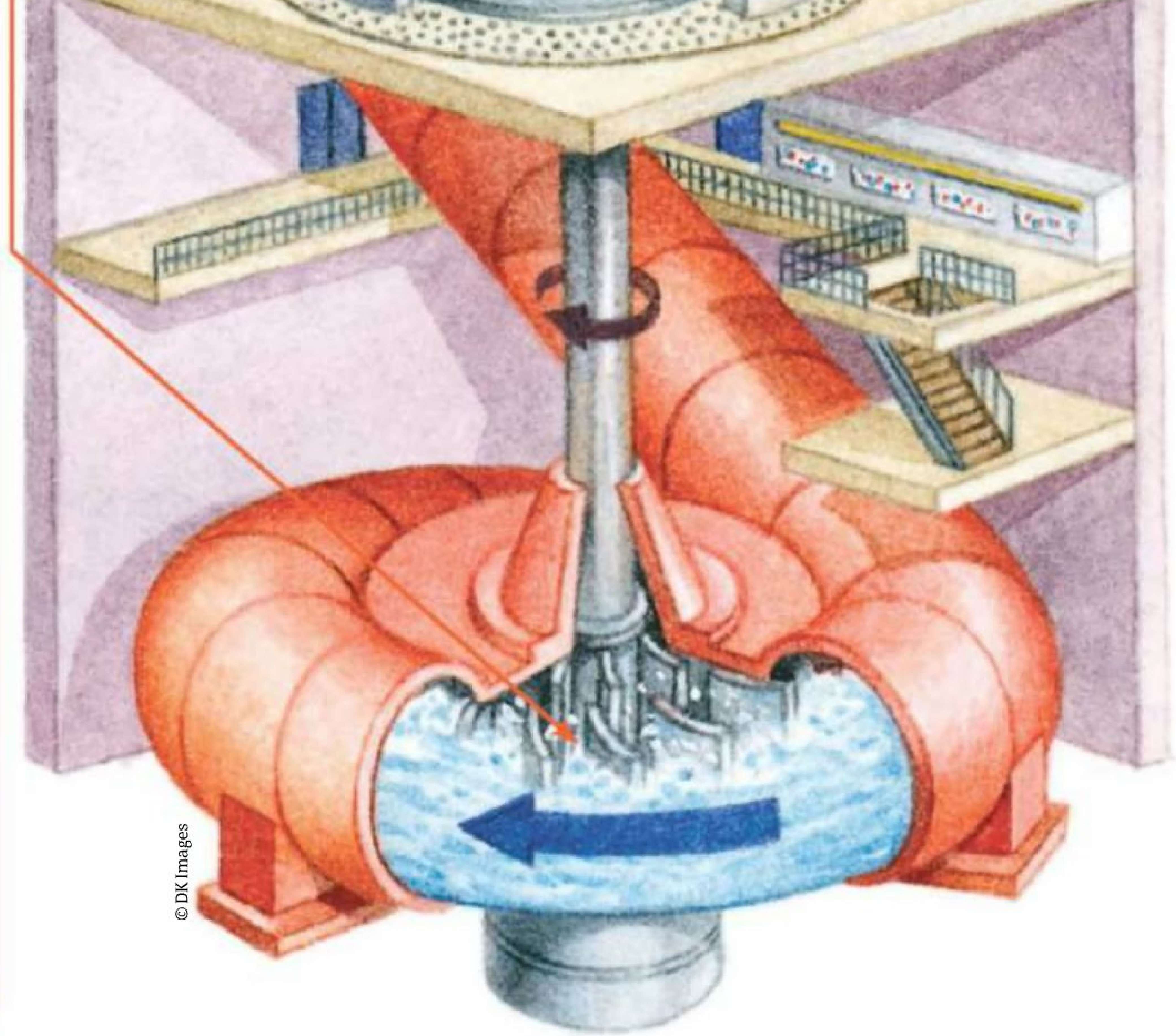
There are two main types of turbine: impulse and reaction. Essentially these names describe the different blade mechanism used. In impulse turbines, where water jets onto the blades, the pressure drop (where the energy transfer occurs) takes place in the convergent guide vanes that direct the fluid onto the rotor blades. The opposite happens in a reaction turbine, where the rotor blades have convergent passages and the pressure drop happens here. Impulse turbines are usually unsuitable for low-head sites because they have low specific speeds, but they're easier to maintain. Reaction turbines can rotate faster given the same head and flow conditions, but generally require a greater level of maintenance.

An early Pelton-type impulse turbine from the late-19th Century

Turbines in context

A lake or river is dammed off and the natural elevation of the site is used to provide the source of the turbine's power

> "Turbines are essentially propellers in reverse, both of which work in direct accordance to Isaac Newton's third law"

Turbine
A turbine (often several are used) is turned by the force of the falling water.

Transformer
The transformer takes the alternating current created by the generator and transforms it into a higher-voltage electrical current that's transferred to the electricity supplier.

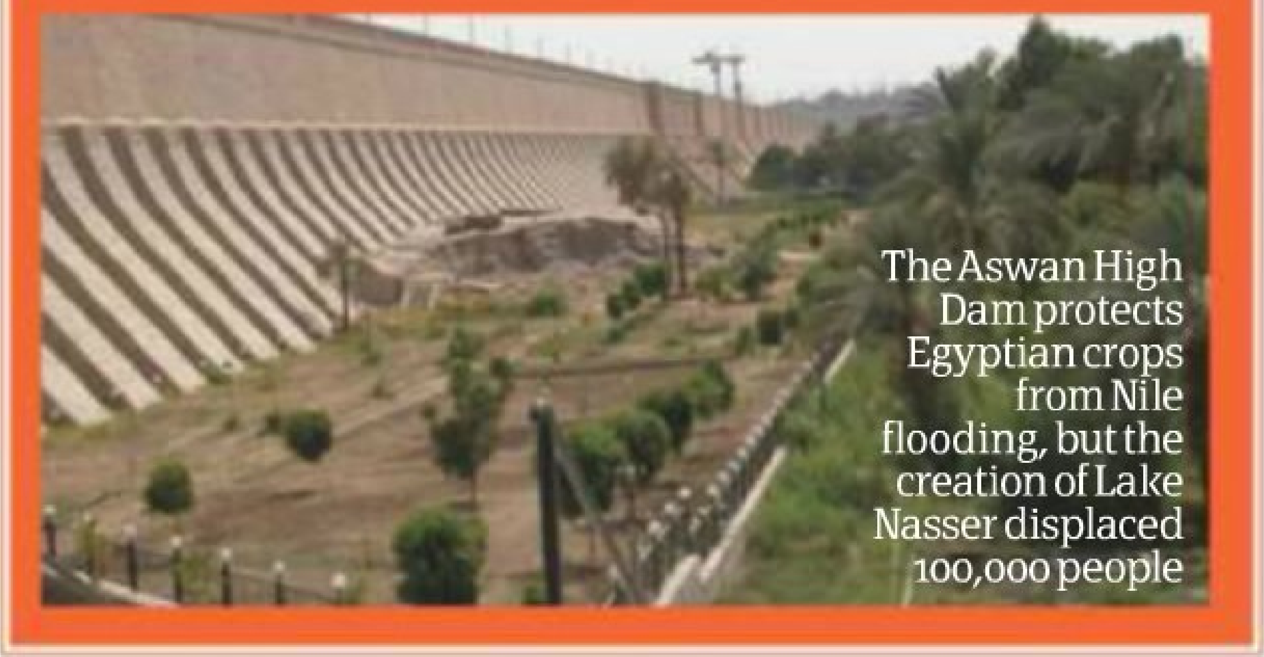
Generator
The turbine turns a series of magnets that rotate past copper coils, moving electrons and generating an alternating current.

Intake
Some form of filtration is necessary prior to the water entering the turbine, to prevent large objects like logs jamming the mechanism.

© DK Images

How green is hydroelectricity?

As a direct source of energy, hydroelectric power by damming a moving body of water and releasing it via a turbine is environmentally friendly. There are no direct waste products and, as long as the water flows, it's an infinite source. But that doesn't mean hydroelectric dams are completely 'green'. Construction aside, a huge area of land is flooded to create the reservoir necessary to drive the turbines, which can upset local plant and animal ecosystems. While the turbine itself has no harmful emissions, the flooded area often drowns vegetation, which then decomposes anaerobically (without oxygen) underwater and produces methane.



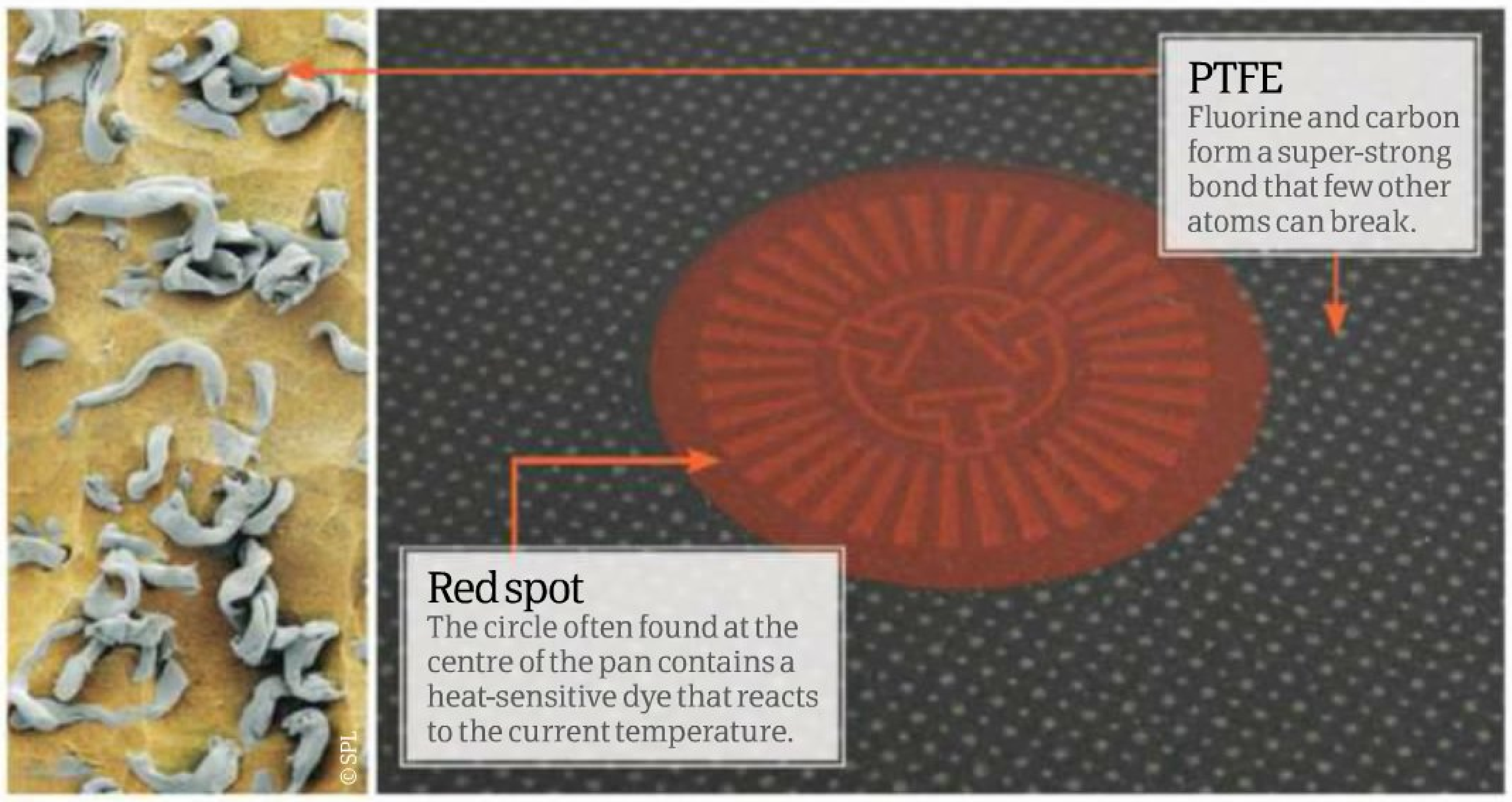
The Aswan High Dam protects Egyptian crops from Nile flooding, but the creation of Lake Nasser displaced 100,000 people

© Ingenieurlösungen

What is Teflon?

Find out why coating cookware in Teflon gives it an amazing non-stick finish

Teflon is made from polytetrafluoroethylene (PTFE) and is used to coat cooking pans giving them non-stick properties. PTFE is composed of carbon and fluorine atoms which form very strong chemical bonds with each other. Fluorine also has the highest electronegativity of any element, meaning the overall electrical forces, known as van der Waals forces, cause compounds containing fluorine to repel any other atoms that come near. The fluorocarbon molecule is structured in a way that the fluorine surrounds the carbon so no other outside atoms can get anywhere near the carbon. As a result Teflon is highly unreactive causing it to have a very low coefficient of friction allowing things to slide across its surface easily. Due to PTFE's reluctance to react with anything, it is also used to coat containers of highly reactive chemicals and, interestingly, is the only known material that a gecko can't stick to.



PTFE
Fluorine and carbon form a super-strong bond that few other atoms can break.

Red spot
The circle often found at the centre of the pan contains a heat-sensitive dye that reacts to the current temperature.

© SPL

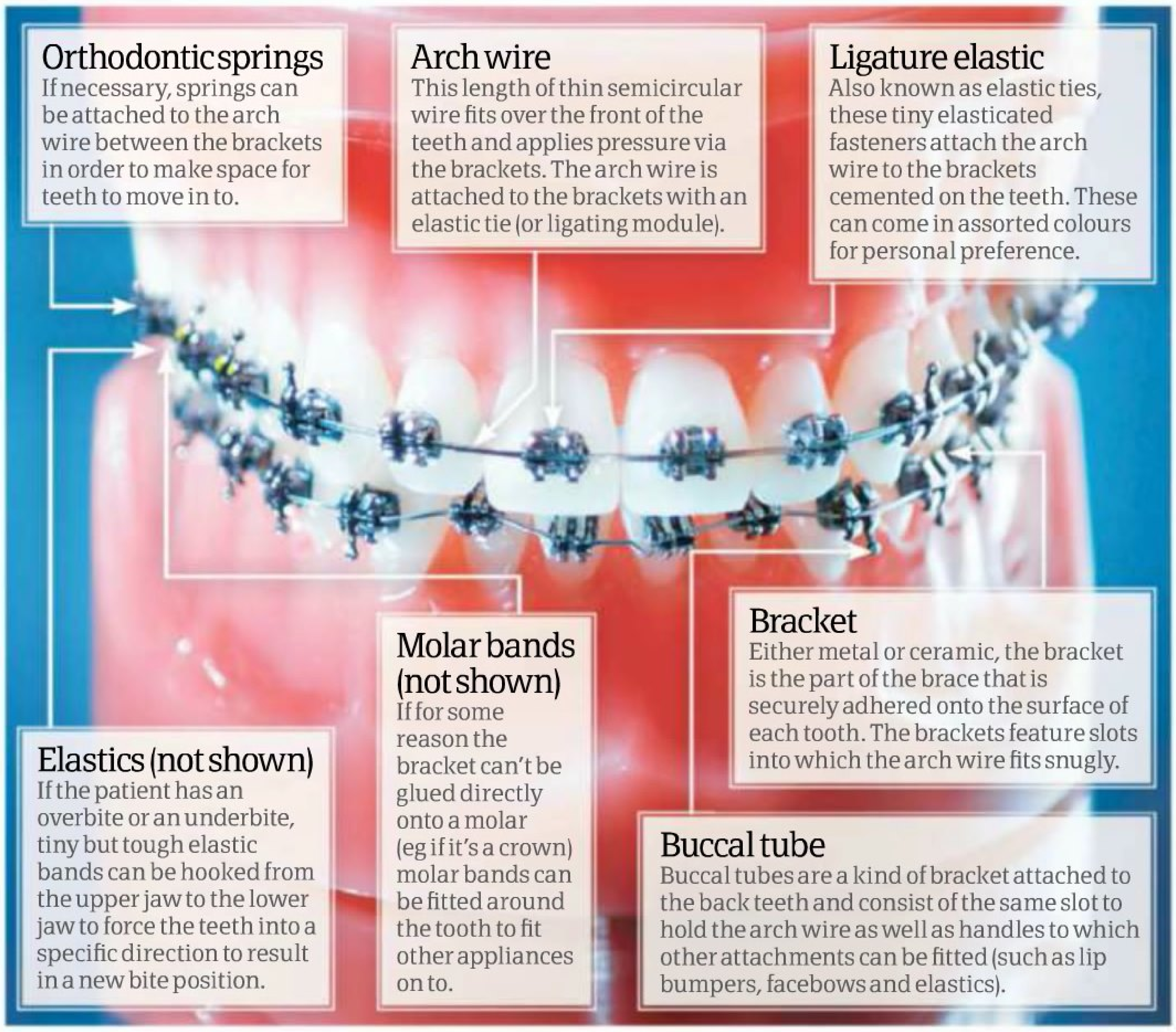
How do braces straighten teeth?

How these metal frames correct the position of misaligned teeth

The literal translation of 'orthodontics' is 'to straighten teeth'. Traditional fixed orthodontic braces can correct crooked teeth, those damaged through injury, or dental abnormalities such as malocclusions or overcrowding. The device consists of a number of metal brackets and wires affixed to the front of each tooth, which then puts sustained pressure on the dentures, gradually moving them into the correct position for a natural or more comfortable bite.

The wires (arch wires) are a type of shape memory metal made from an alloy of titanium and nickel with copper or aluminium. While memory metal is quite malleable at room temperature, it really wants to retain its original shape. When warmed up by heat from the mouth (around 20°C/68°F higher than room temperature) the memory metal is activated. It then stiffens and takes on its original form, which presses against the teeth. Beneath the gum tissue is a layer of collagen fibres known as the periodontal ligaments, which bind the tooth roots to the sockets of the alveolar bone in the jaw. When pressure is put on the tooth, the periodontal membrane will stretch on one side but compress on the other. This loosens the tooth and causes the bone to regrow to support it.

While a tooth under pressure will begin to move after about 72 hours, the bone will not be fully formed for up to three months. So even after a fixed brace has relocated the teeth they must remain supported to enable the bone to fill in.



Orthodontic springs
If necessary, springs can be attached to the arch wire between the brackets in order to make space for teeth to move in to.

Arch wire
This length of thin semicircular wire fits over the front of the teeth and applies pressure via the brackets. The arch wire is attached to the brackets with an elastic tie (or ligating module).

Ligature elastic
Also known as elastic ties, these tiny elasticated fasteners attach the arch wire to the brackets cemented on the teeth. These can come in assorted colours for personal preference.

Elastics (not shown)
If the patient has an overbite or an underbite, tiny but tough elastic bands can be hooked from the upper jaw to the lower jaw to force the teeth into a specific direction to result in a new bite position.

Molar bands (not shown)
If for some reason the bracket can't be glued directly onto a molar (eg if it's a crown) molar bands can be fitted around the tooth to fit other appliances on to.

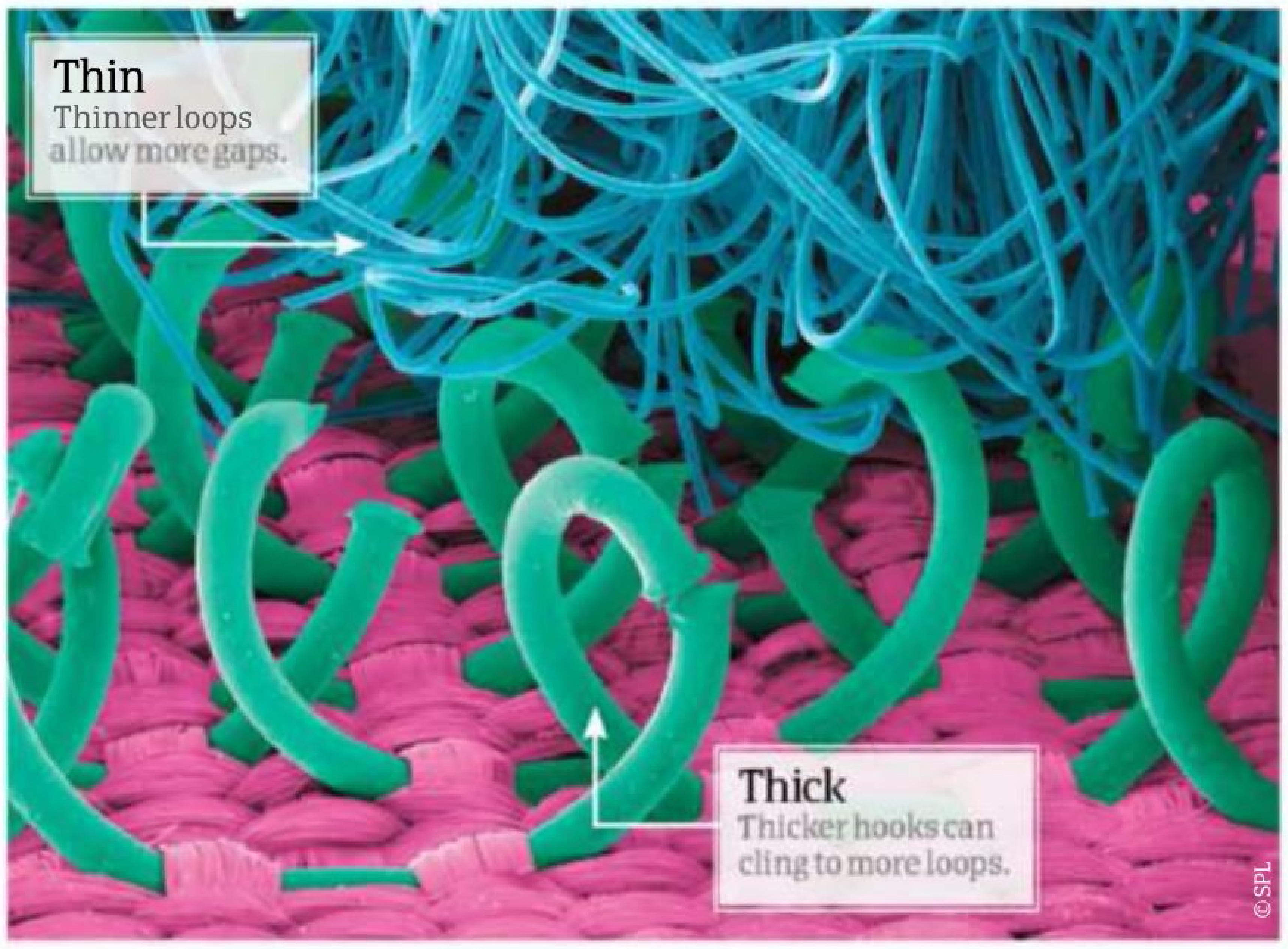
Bracket
Either metal or ceramic, the bracket is the part of the brace that is securely adhered onto the surface of each tooth. The brackets feature slots into which the arch wire fits snugly.

Buccal tube
Buccal tubes are a kind of bracket attached to the back teeth and consist of the same slot to hold the arch wire as well as handles to which other attachments can be fitted (such as lip bumpers, facebows and elastics).

What makes Velcro stick?

Discover the small-scale engineering behind this fastener

Velcro comprises two strips of material – one with lots of tiny hooks, and one with lots of thinner loops – that lock when they are pressed together with force. This mechanism of sticking was inspired by the way tiny hooks on the seeds of burdock, known as burrs, attach to animal fur and human clothing. The hooks and loops in Velcro are commonly made from nylon and polyester with the hooks being more rigid and thicker than the loops. The more hooks and loops that are attached per unit area, the stronger the bond; heavy-duty Velcro contains up to 400 hooks and loops per square inch. In some cases a five-centimetre (two-inch) square piece of Velcro is enough to support a 79-kilogram (175-pound) person. Velcro itself was invented by Swiss electrical engineer George de Mestral in 1948.



Thin
Thinner loops allow more gaps.

Thick
Thicker hooks can cling to more loops.

© SPL

NASA has made extensive use of Velcro since it was conceived

© NASA

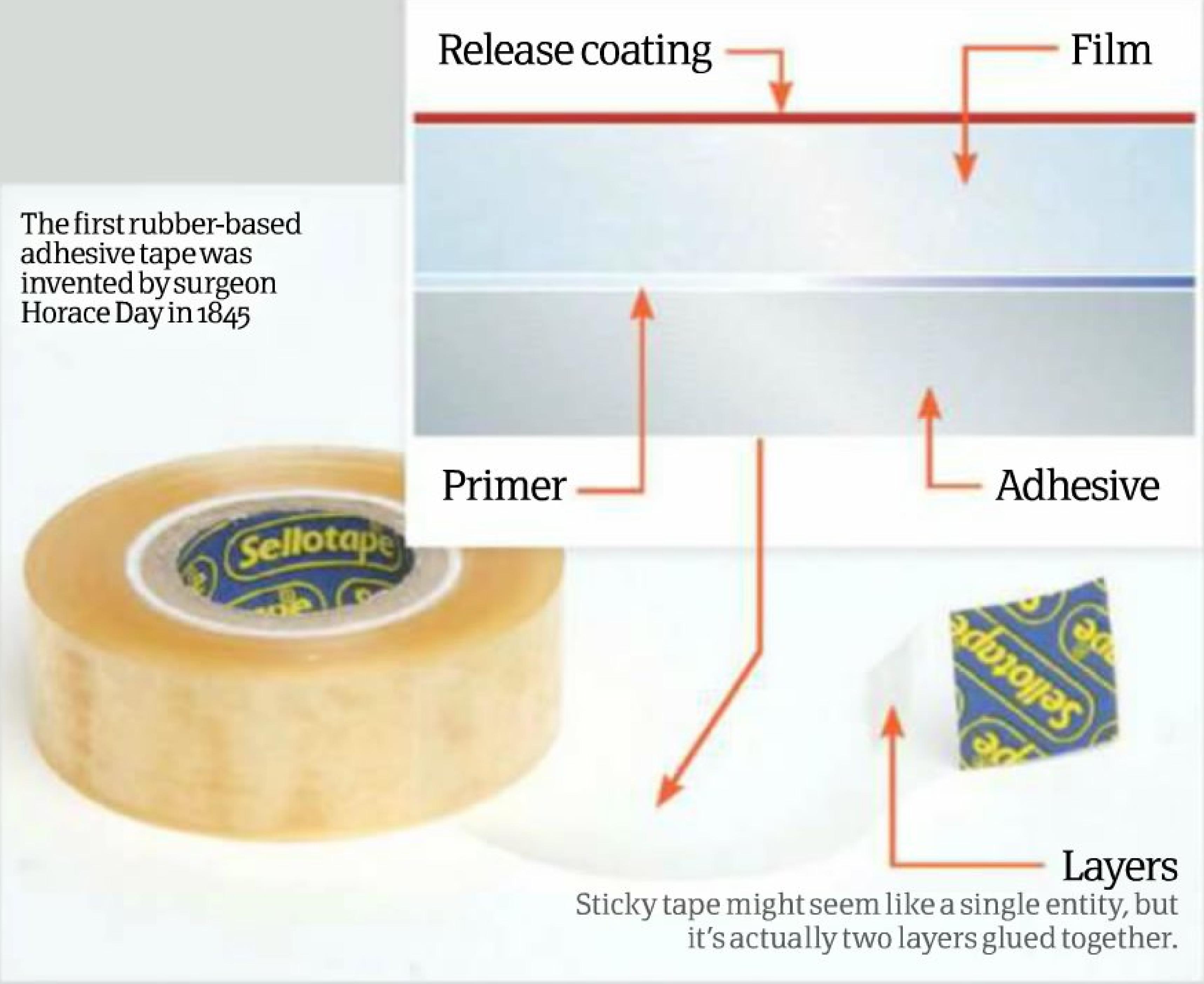
Why is Sellotape sticky?

Discover the amazing properties of sticky tape and how it works

Pressure-sensitive adhesive tape is so versatile because it can stick two surfaces – ideally flat ones – together without the need for heat, solvents or other substances in order to make it tacky. Instead, this amazing invention uses something as simple as a little pressure to make it stick fast. Synthetic transparent cellulose acetate film (historically this was made of natural cellulose derived from plants like cotton or hemp) is made sticky through the addition of synthetic rubber resin, but how are these layers adhered together in the first place?

By first applying a primer to the side of the cellophane film that will host the adhesive, the manufacturers can then apply a very thin layer of the rubber-based glue. Next, by heating or applying hot air to the tape, any liquid present in the adhesive will evaporate, leaving behind a purer dose of glue. Some other types of sticky tape involve laminating the glue to the tape using extreme pressure. The tape is then rolled onto a cardboard barrel for easy dispensing – often with the use of a clever device which keeps that elusive end of the tape accessible for the user.

The first rubber-based adhesive tape was invented by surgeon Horace Day in 1845



Layers
Sticky tape might seem like a single entity, but it's actually two layers glued together.

Why do pressure washers clean so well?

Why does blasting grime with pressurised water get rid of the dirt that soap alone can't shift?

The basic mechanics of a pressure washer involve squeezing pressurised water through a series of small openings to create a powerful jet of liquid that's capable of dislodging dirt and grime from hard surfaces such as patios, walls and vehicles. Domestic pressure washers are connected to the mains water supply by a hose attached to an intake valve on the outside of the washer. When the unit is switched on, the motor spins an angled swash plate at over 3,000 revolutions per minute. This swash plate is used to transform circular motion into reciprocating (up and down) motion to drive spring-loaded pistons up and down; it is these pistons that are responsible for drawing water into the contraption.

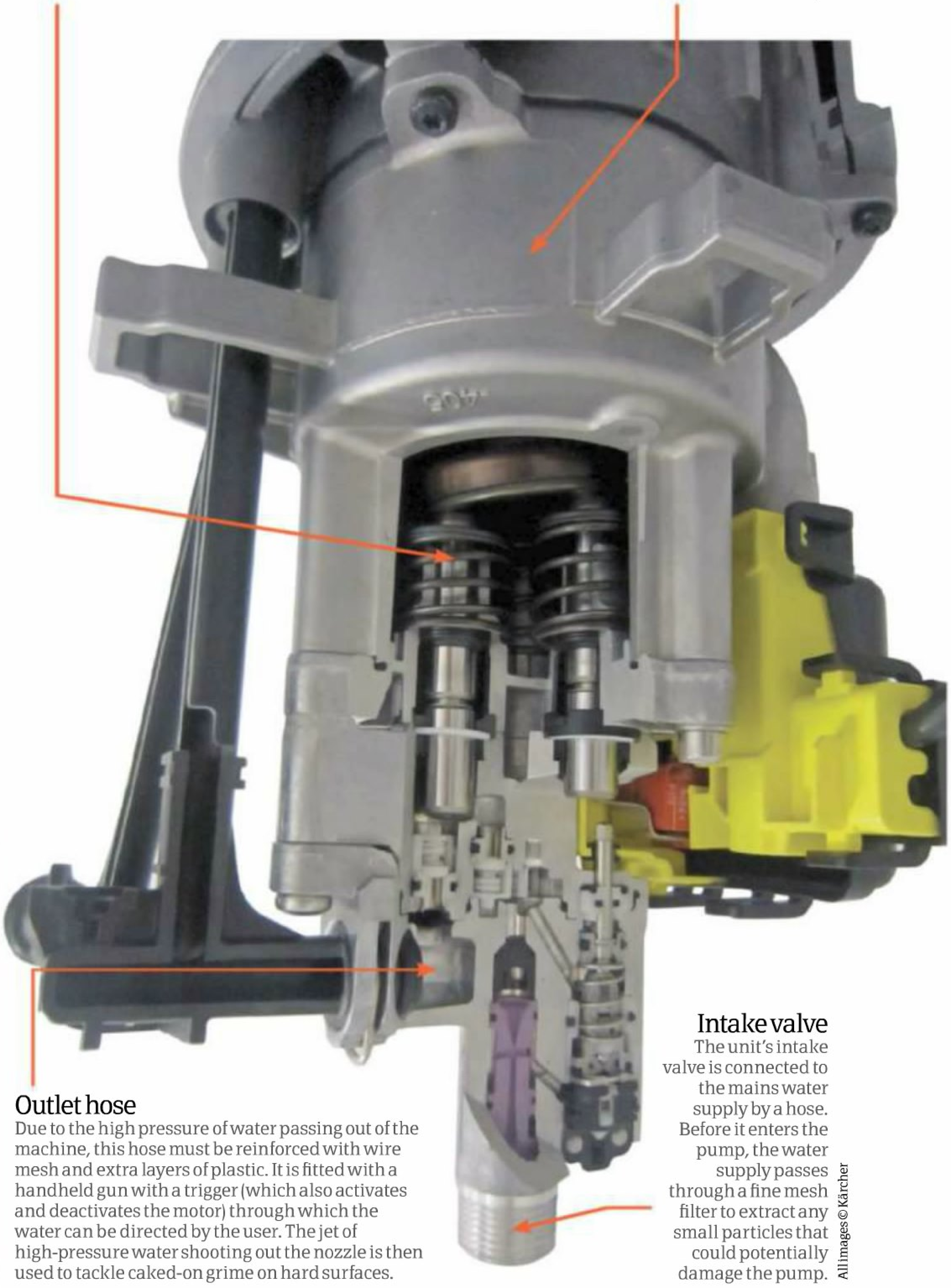
Every time the wide end of the angled swash plate passes, it pushes down on the top of the pistons, causing them to descend. Conversely, when the thin end of the plate passes, the pistons then rise back up to their original positions. The rising of the pistons draws water into the pump through a one-way valve. Because water cannot be squeezed, when pressure is applied it will always naturally proceed to a zone of lower pressure. Therefore when the piston falls and starts to press down on the water that's just entered the pump, the liquid must escape through another one-way valve – this time exiting into the outlet hose under a great deal of force.

The high-pressure water travels at speed along the outlet hose until it hits the closed trigger in the gun. Here the water is blocked – and the motor is temporarily interrupted. When the trigger is pulled by the operator, the motor starts up again, channelling a steady jet of high-pressure, high-speed water out through the tiny hole in the nozzle. This model from Kärcher's wide range of domestic pressure washers features a reservoir for detergents, which have the added benefit of breaking down the dirt further.

Under pressure

As the name suggests, pressure is what drives these machines, but what is it? Pressure is the force applied to a solid, liquid or gas, which causes a substance's molecules to be squashed. The pump in a pressure washer increases the pressure on the liquid, causing the water molecules to bunch together. Unlike air, however, water cannot be compressed, so the crowding water molecules push against the walls of the container. If the fluid can move, when the pressure increases, the molecules have to move towards any point where the pressure is lower; in the case of the pressure washer that means through the outlet valve. Power washers can bump up the pressure of a typical garden hose by 15-50 times, or even more.

Inside the pressure washer's pump



Spring-loaded pistons
Powered by the motor, the pump is driven at high speed to draw water in. This one features a three-piston axial flow pump, which works like a suction pump that draws water in through one end and pushes it out of the pump towards the hose.

Electric motor
The pump inside the pressure washer is driven by a motor that is fed by the mains electricity supply. This model from Kärcher uses a water-cooled induction motor for extra efficiency.

Outlet hose
Due to the high pressure of water passing out of the machine, this hose must be reinforced with wire mesh and extra layers of plastic. It is fitted with a handheld gun with a trigger (which also activates and deactivates the motor) through which the water can be directed by the user. The jet of high-pressure water shooting out the nozzle is then used to tackle caked-on grime on hard surfaces.

Intake valve
The unit's intake valve is connected to the mains water supply by a hose. Before it enters the pump, the water supply passes through a fine mesh filter to extract any small particles that could potentially damage the pump.

All images © Kärcher

How do inhalers help asthmatics?

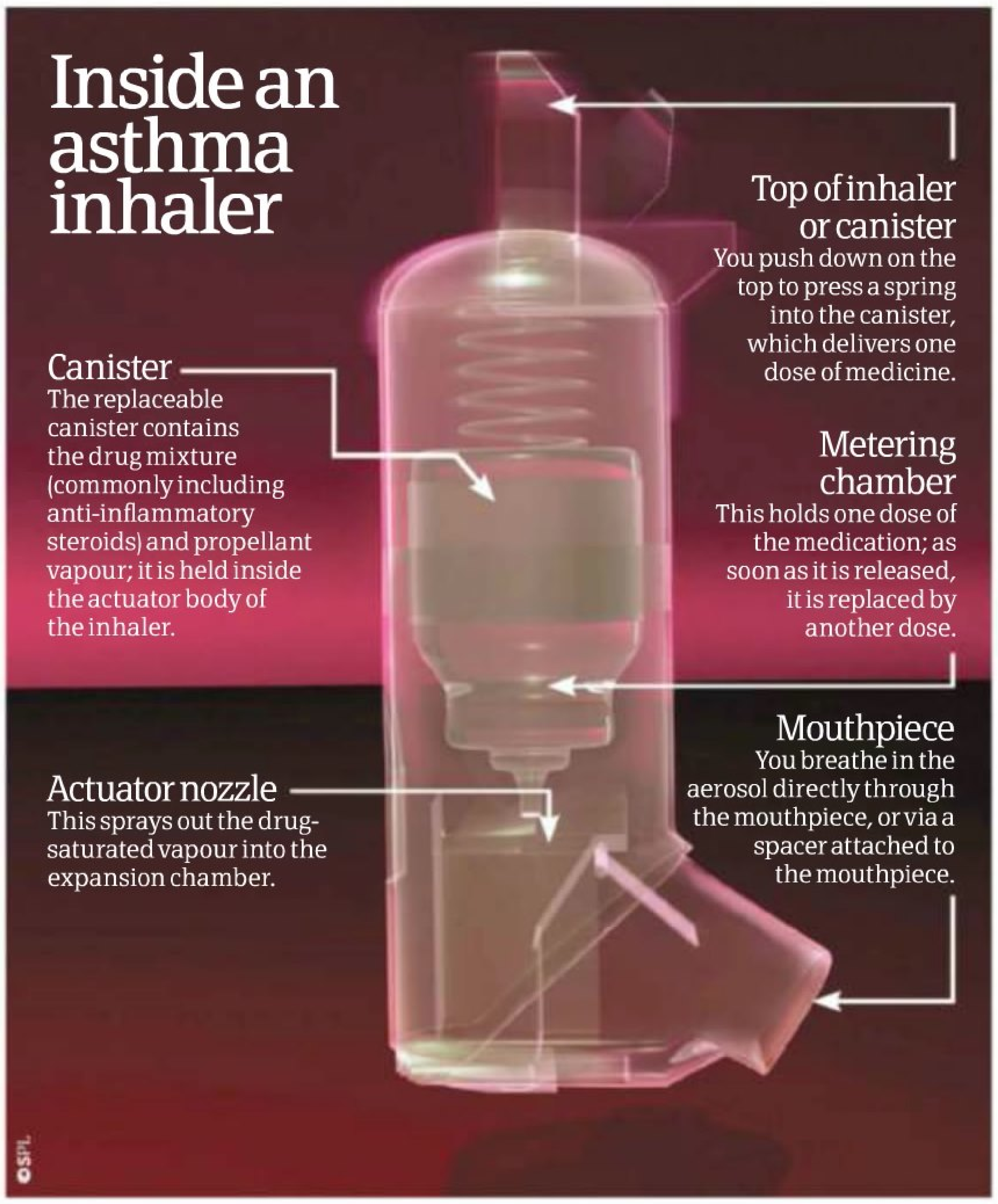
Why this portable device is something no asthma sufferer should be without

Metered-dose inhalers (MDIs) are small hand-operated devices that can send out an aerosol with a precise amount of medication into a small chamber. The user then breathes in the drugs through the mouthpiece, and the medication goes directly to the airways and lungs.

The inhaler, or puffer, consists of a plastic body and a pressurised canister that contains the medication and a propellant vapour. Large plastic, valved holding chambers, or spacers, can be fitted to the mouthpiece of the inhaler, if desired, so that the user has more time to inhale the aerosol. For the treatment of asthma, the user usually has two colour-coded inhalers. One is a 'preventer' inhaler which contains medication that has to be used on a regular basis, and the other is a 'reliever'; the latter is used in the event of breathlessness or a sudden asthma attack.

This humble-looking gadget has saved many lives

Inside an asthma inhaler


Top of inhaler or canister
You push down on the top to press a spring into the canister, which delivers one dose of medicine.

Canister
The replaceable canister contains the drug mixture (commonly including anti-inflammatory steroids) and propellant vapour; it is held inside the actuator body of the inhaler.

Metering chamber
This holds one dose of the medication; as soon as it is released, it is replaced by another dose.

Actuator nozzle
This sprays out the drug-saturated vapour into the expansion chamber.

Mouthpiece
You breathe in the aerosol directly through the mouthpiece, or via a spacer attached to the mouthpiece.

© SPL

What's inside a jukebox?

Combining the traditional Fifties jukebox look with the convenience and quality of CD technology

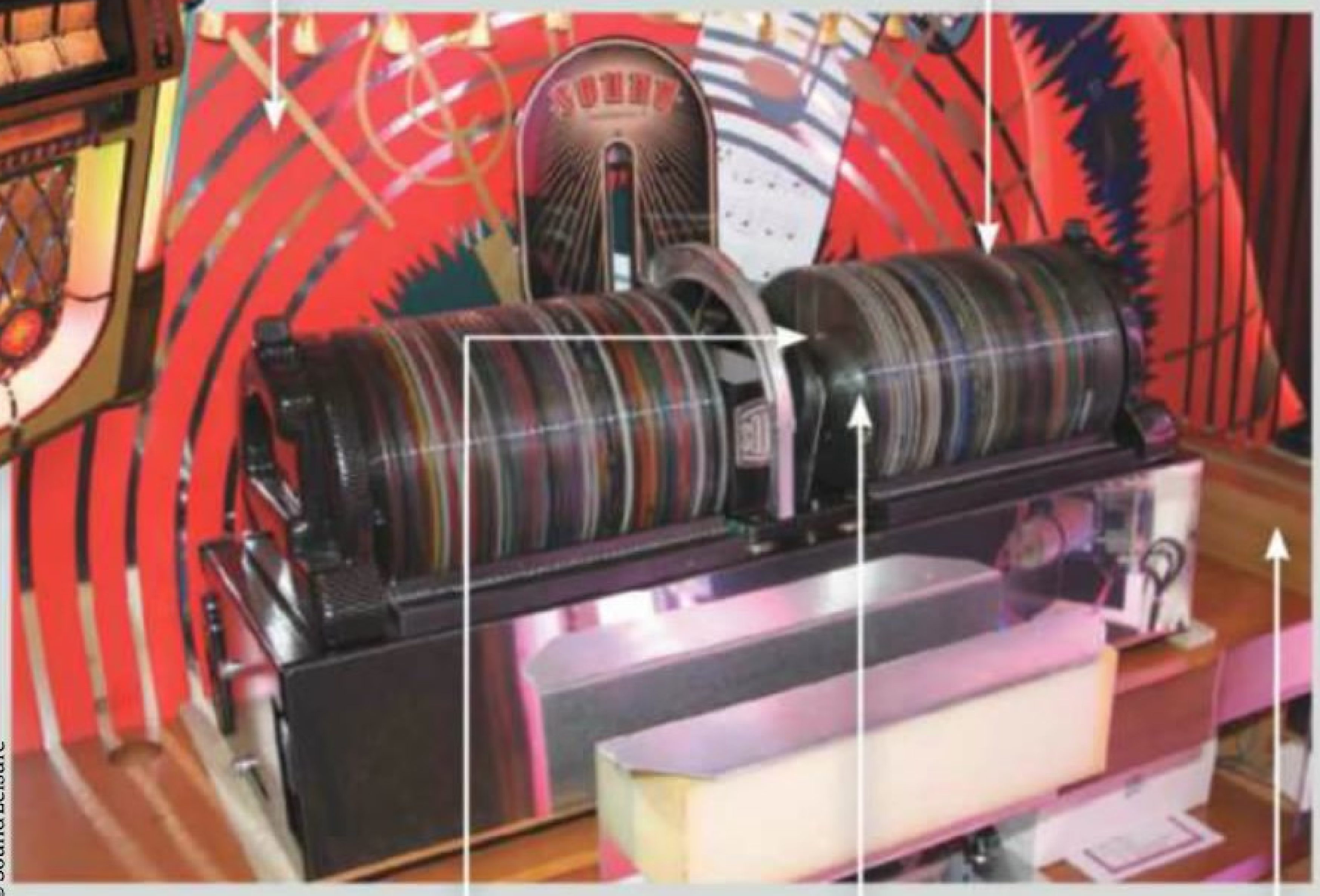
This type of jukebox, with a 21st-Century inner mechanism, holds 80 compact discs (CDs) stacked horizontally on a slotted rack. When switched on, the pick-up mechanism runs on a track to the end of the rack, and then a sensor sends it 40 spaces to the centre of the rack. After a CD or song is selected on the panel of the jukebox, or via a remote-control unit, a location wheel on the pick-up mechanism sends it along its track to the correct CD location.

The pick-up mechanism lifts the selected disc, takes it back to the centre of the jukebox, and drops it down to the playback head. The CD playing head will scan the number of tracks on that disc and play the one that was selected. Once the track has finished the CD is lifted and returned to its original slot and the selection process is ready to start all over again.

Inside a CD jukebox

Domed top
The 'bubbler' top is styled after the classic 1946 Model 1015.

CD rack
80 CDs are stacked vertically ready to be selected.



Pick-up mechanism
A notched belt drive sends this along its track to select a CD. A location wheel that sends out a pulse every time it passes each CD slot guides it to the correct position.

Playback
The CD is lowered into the playback mechanism. This clamps the disc in position, scans it and plays the chosen track.

Cabinet
A loudspeaker dominates the space below the top. Decorative tubes contain methylene chloride that is heated to generate a gas that creates a bubble effect.

2x © Sound Leisure

How can flood barriers protect cities?

A closer look at how these mechanical defences are able to hold back great surges of water

Flood barriers are employed all over the world to prevent a sudden deluge of water from damaging property and potentially taking lives. A few sandbags lining the floor of a porch will be an effective defence against a small flash flood, but something a little more robust is required to hold back the mighty swell of a river such as London's Thames.

In 1953, London and the surrounding area was hit by a flood that claimed 307 lives and caused millions of pounds' worth of damage. It prompted the creation of the Thames Barrier, an impressive feat of engineering that took eight years to build and cost £534 million ($839 million) by the time it was completed in 1982. It stretches across 520 metres (1,706 feet) of the Thames near Woolwich and comprises ten separate gates on pivots supported by concrete piers that house the machinery for operation of the gates.

As tends to be the case with all the best engineering designs, the Thames Barrier is based on a very simple concept. Each gate is radial, using hollow cylinders that rotate the barrier through 90 degrees according to whether they're in open, flood control or maintenance positions. Four central gates over 20 metres (65 feet) high and weighing 3,300 tons each span the middle section of the barrier, with two smaller gates next to them and four non-navigable radial gates that sit above the river during normal flow.

When a potential storm is forecast to hit the Thames Estuary, the barrier flood defence can be erected in around 90 minutes. Two hydraulic cylinders move rocking beams that shift the gate into the closed position. Here, the Thames Barrier can hold back the downstream tide until it's level with upstream again and the decision is made that it is safe to be opened once more.

Stormy waters

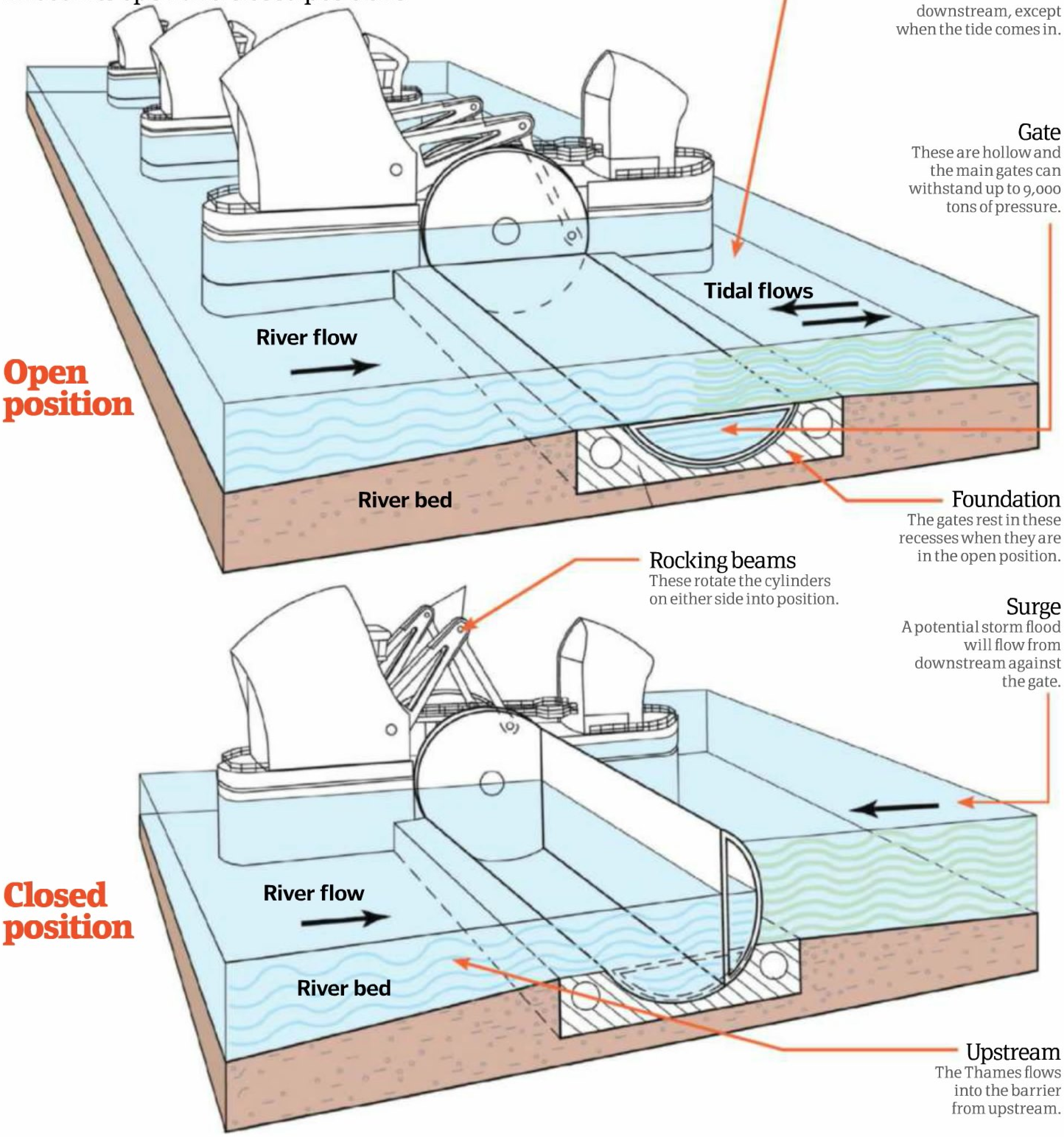
The 1953 North Sea Flood was one of the worst natural disasters to happen in the UK in recorded history. It occurred when a high spring tide combined with a severe storm over the North Sea, sending a swell that was magnified in the narrow estuarine channels along the coast. In places it reached up to 3.2 kilometres (two miles) inland, destroying 24,000 properties, 1,600 kilometres (994 miles) of coastline and flooding 1,000 square kilometres (386 square miles).

The Netherlands – parts of which lie below sea level – was even worse hit: the country's sea defences buckled under the pressure and killed 1,835 people, 30,000 animals and caused over a billion Dutch guilders (about £360 million/$570 million) of damage.

The Thames Flood Barrier has been in operation since 1982 and protects 125km2 (48mi2) of central London from tidal surges

The Thames Barrier in action

Explore London's impressive flood defence in both its open and closed positions



Downstream The river flows away from the barrier downstream, except when the tide comes in.

Gate These are hollow and the main gates can withstand up to 9,000 tons of pressure.

Foundation The gates rest in these recesses when they are in the open position.

Rocking beams These rotate the cylinders on either side into position.

Surge A potential storm flood will flow from downstream against the gate.

Upstream The Thames flows into the barrier from upstream.

The biggest barrier

The Oosterscheldekering is the largest movable flood barrier in the world. Like the Thames Barrier, this Dutch feat of engineering was built in response to the 1953 North Sea Flood. It's actually part of 13 dams known as Delta Works and is nine kilometres (5.6 miles) long, four kilometres (2.5 miles) of which include huge sluice-gate doors that are normally open, but can be closed in the event of a tidal surge. It comprises 65 concrete pillars weighing 18,000 tons each, with 62 steel doors, each 42 metres (138 feet) wide. Dutch engineers created an artificial island in the centre of the estuary to facilitate the construction of the structure and, unlike the Thames Barrier, which is estimated to be effective until around 2030, Oosterscheldekering has a predicted lifetime of 200 years.

© Alamy; Thinkstock; Rens Jacobs; John Webber

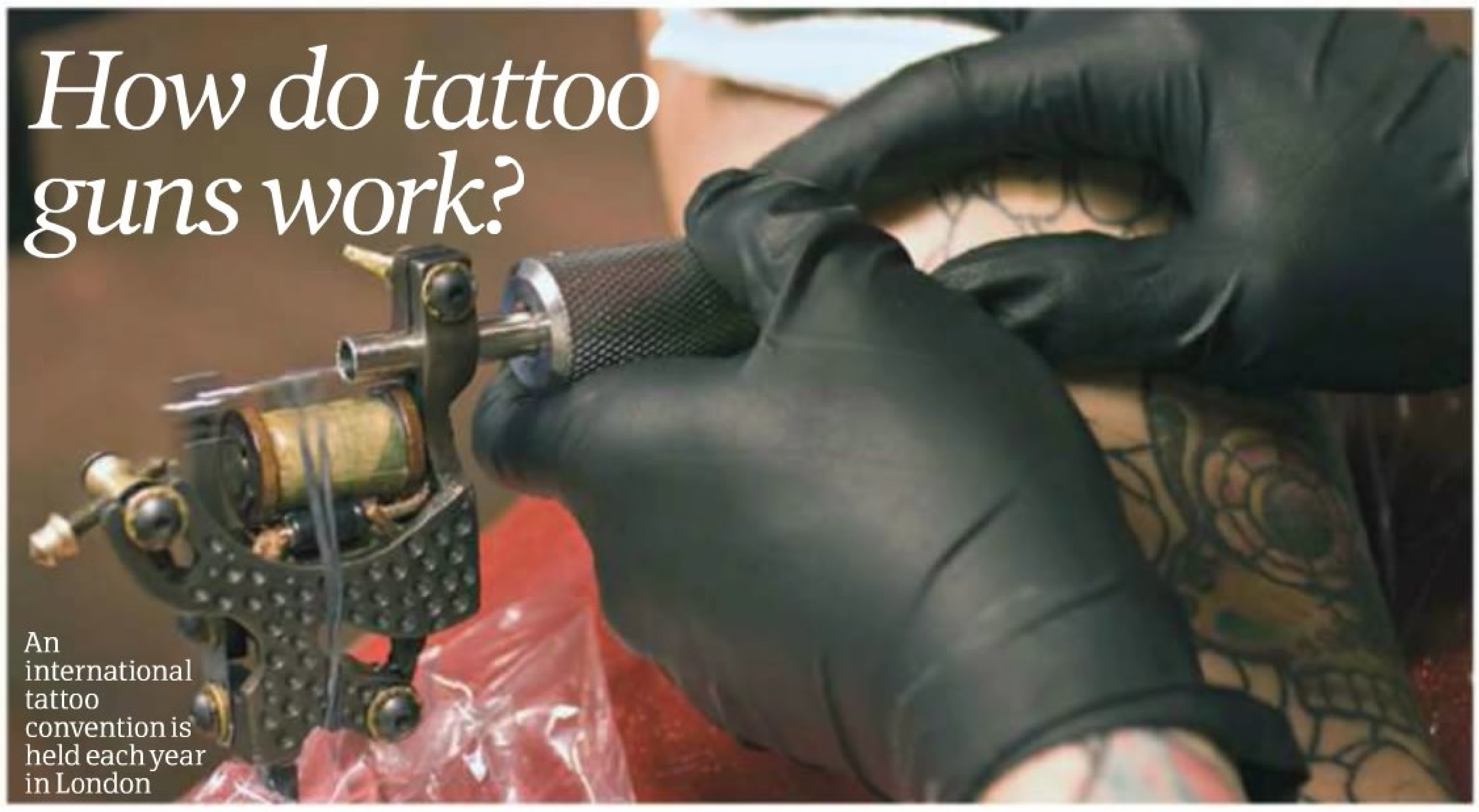
How does memory foam stay in shape?

One of the most widely used NASA spin-off inventions, memory foam – also known as 'temper foam' and 'slow spring-back foam' – was originally designed with aircraft seat safety and protecting astronauts from g-forces and collisions in mind. This special plastic foam has the ability to deform under extreme pressure, absorbing the energy from crashes and providing shock absorbency while also returning to its original shape.

A foam can be a solid or a liquid that contains trapped bubbles of gas inside it. Memory foam is a solid visco-elastic foam – 'visco' (as in viscous) means that it moves when you apply pressure, and 'elastic' means it returns to its original shape when you remove that pressure. This particular foam is made from open-cell polyurethane, which is a synthetic polymer that features a network of tiny pores or bubbles that shift under pressure, rather than merely compressing. Memory foam responds to changes in temperature and tends to be firmer when it's cool but softer when it's warm. Upon applying pressure, the foam distributes the weight placed on top of it. This material has since been used for many other useful applications, such as mattresses, crash helmets, and even prosthetics.

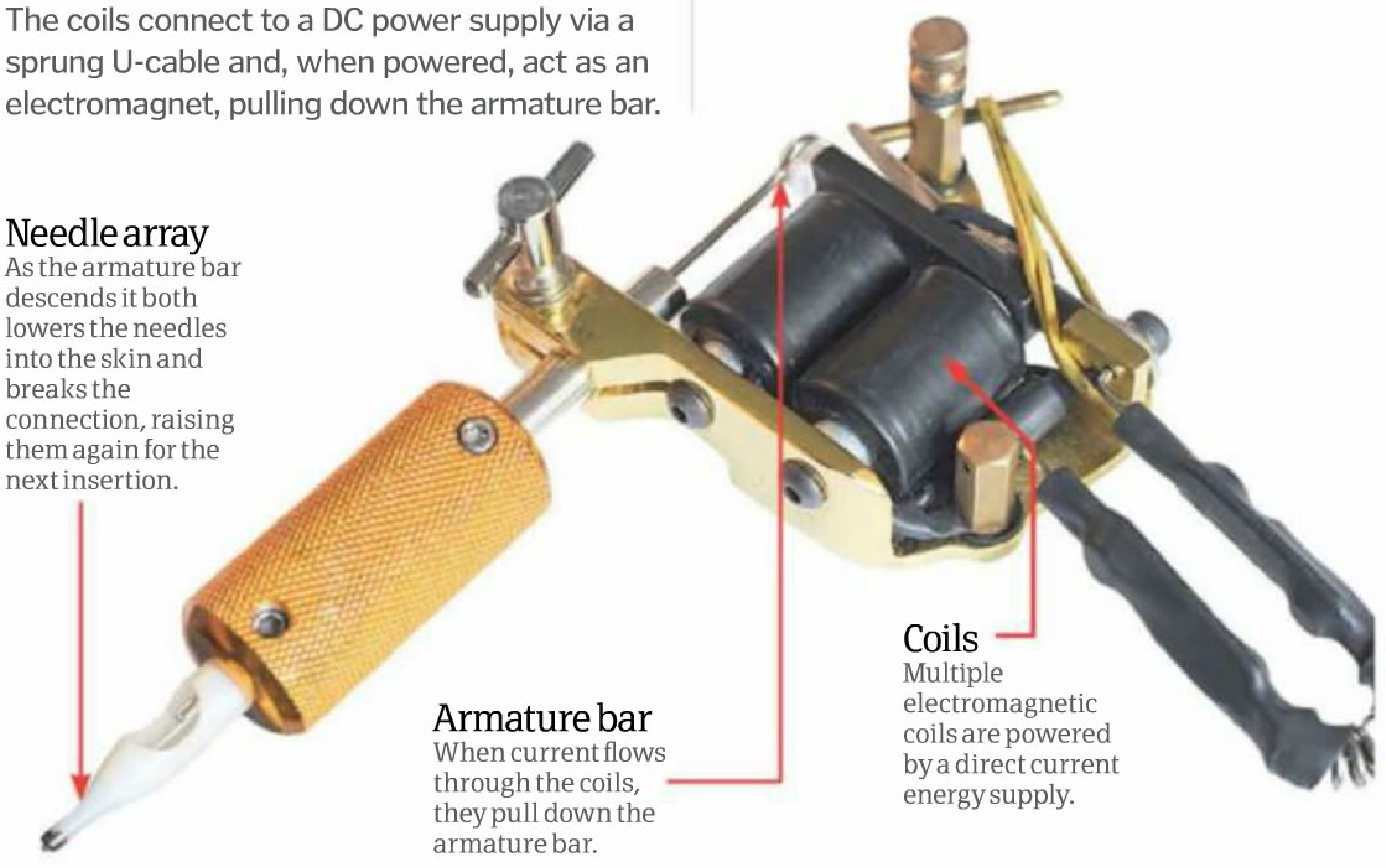
© SciencePhotoLibrary

How do tattoo guns work?


An international tattoo convention is held each year in London

Tattoo guns, also commonly known as tattoo irons or machines, come in a variety of forms. The most common variant, however, is the coil type, which utilises a series of electromagnetic coils to raise and lower needles into the skin to deposit the ink. These devices work by connecting an armature bar via a spring to a base unit, which itself contains between one and three electromagnetic coils. The coils connect to a DC power supply via a sprung U-cable and, when powered, act as an electromagnet, pulling down the armature bar.

Attached to the armature bar is the machine's needle array, and as it descends so too do the needles, piercing the skin and depositing ink just below the surface. At the bottom of the bar's descent its connection with the electromagnet breaks and, as a result, it lifts back to the default position. As such, the needles are constantly drawn up and down at a high speed in a cycle.


Needle array
As the armature bar descends it both lowers the needles into the skin and breaks the connection, raising them again for the next insertion.

Armature bar
When current flows through the coils, they pull down the armature bar.

Coils
Multiple electromagnetic coils are powered by a direct current energy supply.

How do rewritable CDs work?

A normal CD has a surface covered in microscopic bumps where a bump will signify a '0' and a flat will signify a '1' in the binary system and this is how data is read. This has to be different for a rewritable disc though. For this a dye is used to coat the surface. When writing on the CD, the dye will either be opaque or clear with the two states representing the binary number system. The dye is designed to change between opaque and clear so the disc can be rewritten over several times, helping you transfer more data.

When will videogames look like real life?

In some respects, the CG animations used in videogame cut-scenes can already look uncannily realistic. However, the human eye works differently to a monitor, and the brain very differently to a computer, so the way we perceive realism and the way we re-create it are hard to compare. For starters, our eyes and retinas are curved. So although we can easily calculate, say, the screen resolution of a videogame in dots per inch (dpi), that assumes viewing it on a flat screen of a fixed size at a fixed distance. However, human vision works in arcs – an object's sharpness and clarity appearing minutely different depending on how close it is. Today's videogames and monitors can comfortably handle resolutions of up to 1,920 x 1,080 dpi, but the human eye is capable of seeing much more subtle detail. Videogames are also viewed on a single screen whereas we see the world with two eyes that cover much wider peripheral vision.

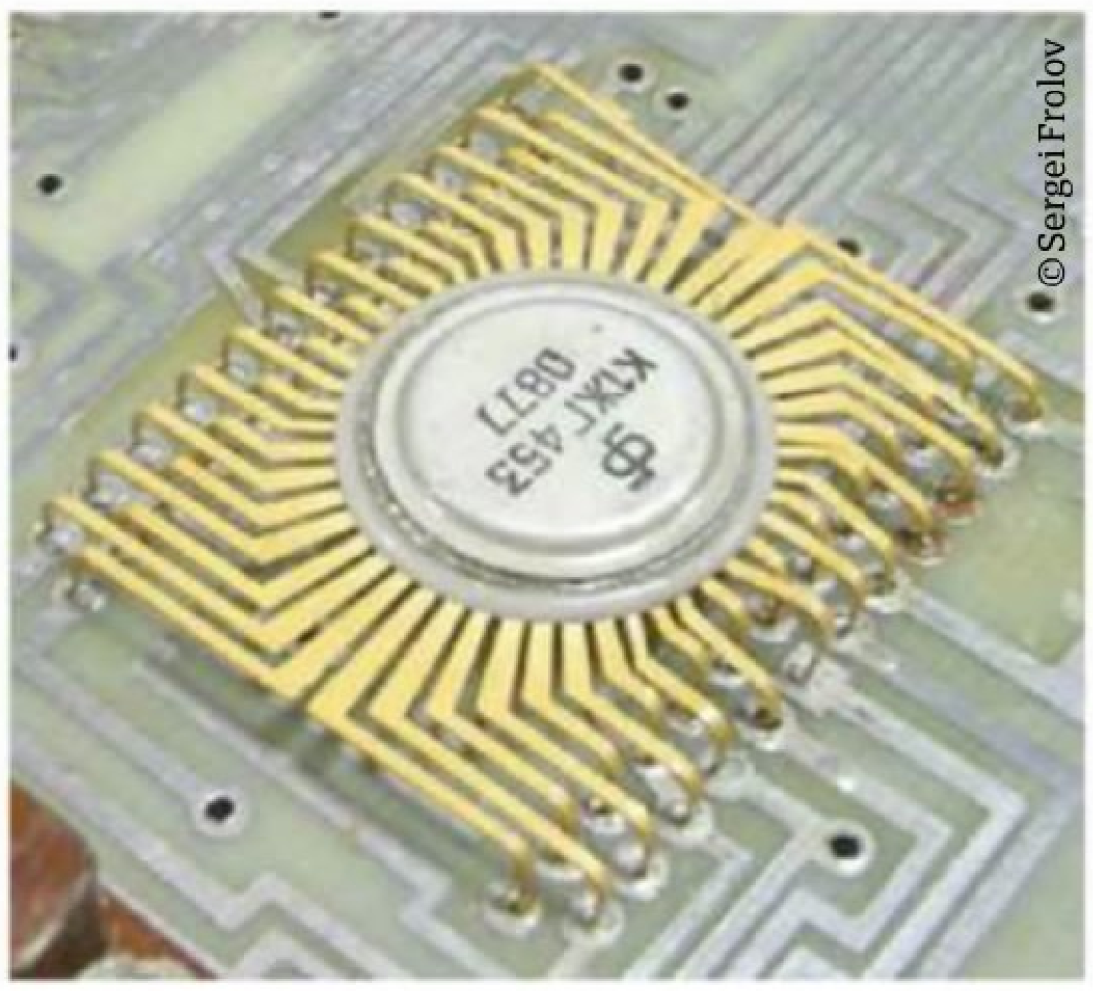
How does your voicemail record voice messages?

Voicemail works by monitoring the electromagnetic waves that are used to carry phone signals. If you are busy, or your phone is off, the message is stored in a 'mailbox', essentially another line to which calls are diverted after a certain amount of time. This mailbox records the exact nature of the electromagnetic wave that was sent, including the differences in volume and frequency in the human voice.

These impulses are then encoded into ASCII, a binary system that renders them into 0s and 1s. Once this is done, the phone is capable of playing it back as a stream of binary data, which includes the frequency and volume of the voice that left the message. When you hit playback, the resonating elements of the phone, including the speaker, use that stream of binary code to re-create the message.

Why are microchips made of silicon?

Most microchips are currently made from silicon due to its effective semi-conducting properties. A semiconductor is something which conducts electricity, but only partially. Semiconductors are the foundation of most electronic devices as they allow the building of gates and switches in a circuit. Pure silicon is actually an insulator, and becomes a semiconductor through a process known as doping. Doping involves introducing small amounts of impurities, giving rise to free electrons or 'holes' that electrons want to move into. Silicon has been so widely used in microchips as it is easy to extract from sand in large quantities, and gets the job done. However current research suggests that materials such as carbon graphene are able to outperform silicon, and could represent the future of consumer electronics.


© Sergei Frolov

IBM's BlueGene/L computer is currently the fastest on Earth

What is super-fast computing?

Super-fast computing is a buzzword yet to catch on as no one has defined exactly what it means. Most experts agree it will involve some form of 'quantum computer', but exactly how such a device is to be constructed is up for debate. Quantum computers would use the unique properties of atoms to perform calculations rather than the current model of transistors and semiconductors. There are several branches of the quantum theory being explored. Scientists in Sydney recently unveiled the world's smallest transistor, created by precisely positioning a single phosphorus atom in a silicon crystal. The consequences of this are profound; atomic semiconductors mean whole computers could be condensed and placed on a pinhead, drawing almost no power yet capable of performing calculations billions of times faster than even today's fastest supercomputer, IBM's BlueGene/L. However, it is estimated that the first fully functional quantum computer is still at least 20 years away.

What is a short circuit?

People usually say 'short circuit' to mean any sort of electrical problem, but it's actually more specific than that. First, let's see what a circuit is: Suppose you have a light bulb connected to a battery. If the light is 'on', there's electricity flowing, coming out of the battery, going through the lightbulb and then back into the battery. This is a circuit.

A short circuit is when electricity doesn't take the path it was meant to – for example, if two bare wires touch. This causes a lot of electricity to surge at that point of contact, which causes the wires to get very hot.

Unlike yesteryears, modern cameras have no film in them

How do digital cameras capture images without using any film?

Instead of film, digital cameras use an electronic detector to register light. There are different types of sensors, but the main thing is that when light particles (photons) hit it, electrons get out, creating an electric signal. The sensor is divided into tiny areas called pixels. These are the small dots or squares you can see in the picture. On most cameras, different pixels receive light for red, green or blue. A basic computer built into the camera converts the signals from the pixels into an image that can be understood and read by a computer.

> "The main thing is that when light particles hit the sensors, electrons get out, creating an electric signal"

How does a scanner work?

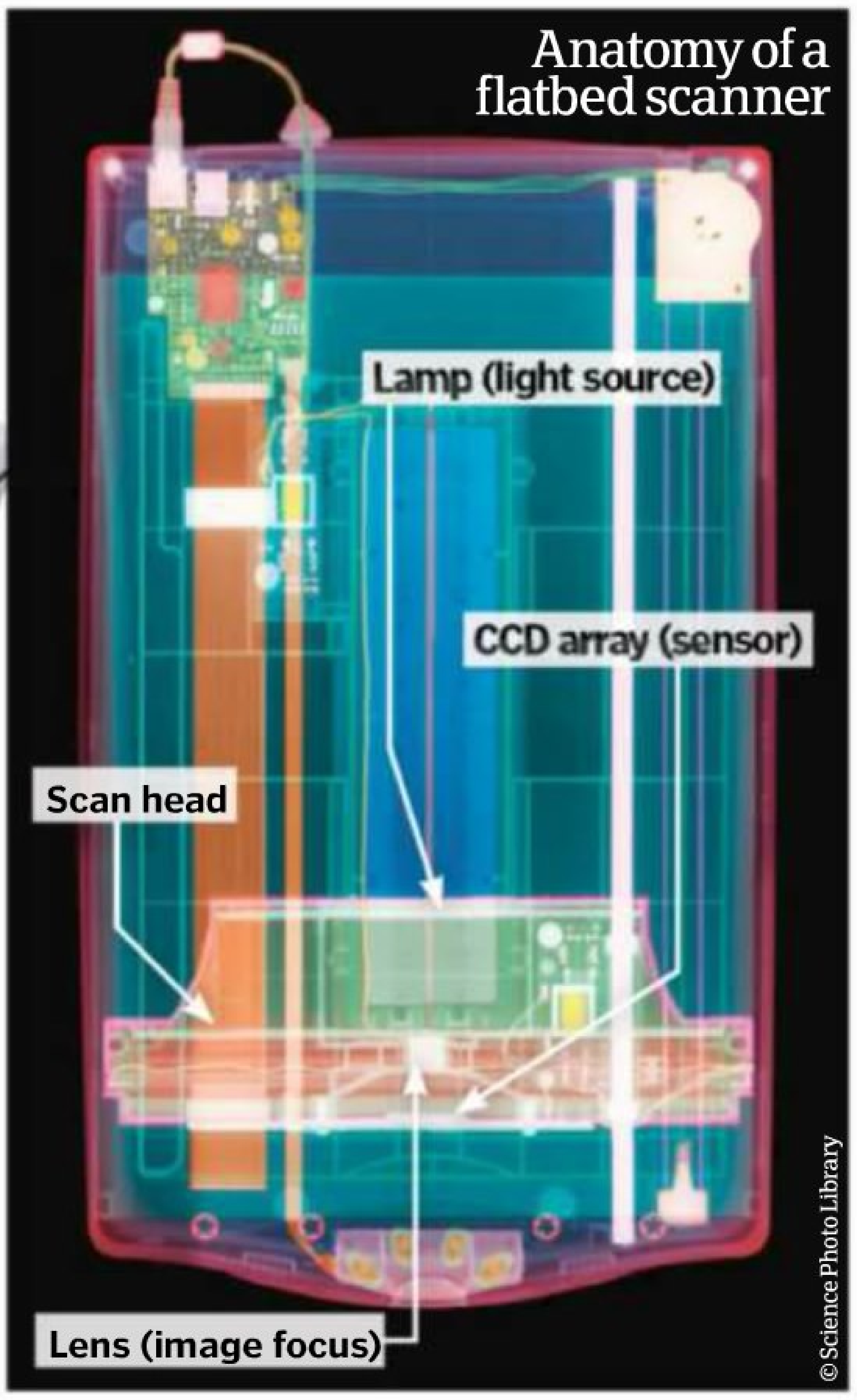
Flatbed scanners use a beam of light, mirrors, a focusing lens, filters and a sensor called a charge-coupled device (CCD) array to capture the image of a physical photo or other paper document and convert it into a digital file for use on your computer.

The lamp and mirrors are part of the scan head, which is a sliding mechanism that slowly passes beneath the document to be digitised. Once you have placed the paper face down on the flat glass bed, closed the lid and pressed 'scan', the scan head will begin to pass underneath the page. As it does so, the lamp casts a bright beam of light onto the document above to illuminate it. The first mirror on the scan head – positioned just behind the lamp as it passes by the document – is angled so that it reflects the now-illuminated part of the page onto a second mirror. The second mirror then reflects the image onto a third.

New scanners contain special character-recognition software that can translate handwriting into digital text

Each mirror is slightly concave which means that the image becomes progressively smaller as it is reflected from one mirror to the next in the chain.

At this point the significantly scaled-down picture is reflected from the last mirror through a lens to focus the light through colour filters (usually red, green and blue) and onto the sensor. This sensor (the CCD array) consists of numerous light-sensitive diodes, which convert light energy (photons) into electrical energy (electrons). This produces an electronic, or digital, version of the image, which you can then port to your computer where you can edit, reprint and/or distribute the file through various means.



Anatomy of a flatbed scanner

© Science Photo Library

© Orion

The same mechanism that is used in traditional firearms was only slightly adapted for the flare gun

How do flare guns work?

A flare gun works in the same way as any traditional firearm with one key difference: it must ignite its projectile and propel it high into the sky. Generally credited to Edward Very (1847-1910), the first gun that could fire a flare was tested by the American Navy back in 1882.

When the trigger of a flare gun is pulled, a chain of events begins. First, the flare's propellant is ignited as the gun's hammer strikes the detonator cap. The signal is then pushed out of the gun's barrel through deflagration, which is a subsonic combustion process where an intense burning of gases in a small space generates great pressure.

The short time it takes to ignite the propellant is enough for the flare to also be lit. These objects burn so brightly because they contain magnesium, an element also used in fireworks. Other chemical additives can produce varying colours. In some cases, the flare will also have an inbuilt parachute (most commonly for military use) that prolongs its fall to Earth and extends the average 40-second period that a flare will typically burn brightly for.

What is RAM?

Random access memory (RAM) is a type of physical data storage that can be used to read and write data to so it can be accessed by a computer's CPU (central processing unit). RAM is considerably faster than the hard disk drive memory used to store files and, as such, allows data to be processed more efficiently. Importantly, unlike hard disk memory, RAM is volatile and does not retain information after power is cut to the machine, resetting for future usage. Today, DDR SDRAM – or double data rate synchronous random access memory – is popular as it provides a high bandwidth for fast reading and writing. Apart from its conventional use in PC's, today RAM is also present on most smartphones.

How does Wi-Fi work?

Most people use a router to connect to the internet. This gadget sends and receives information from a phone line or TV cable, and can handle this information, connecting to several computers around the house or office at the same time.

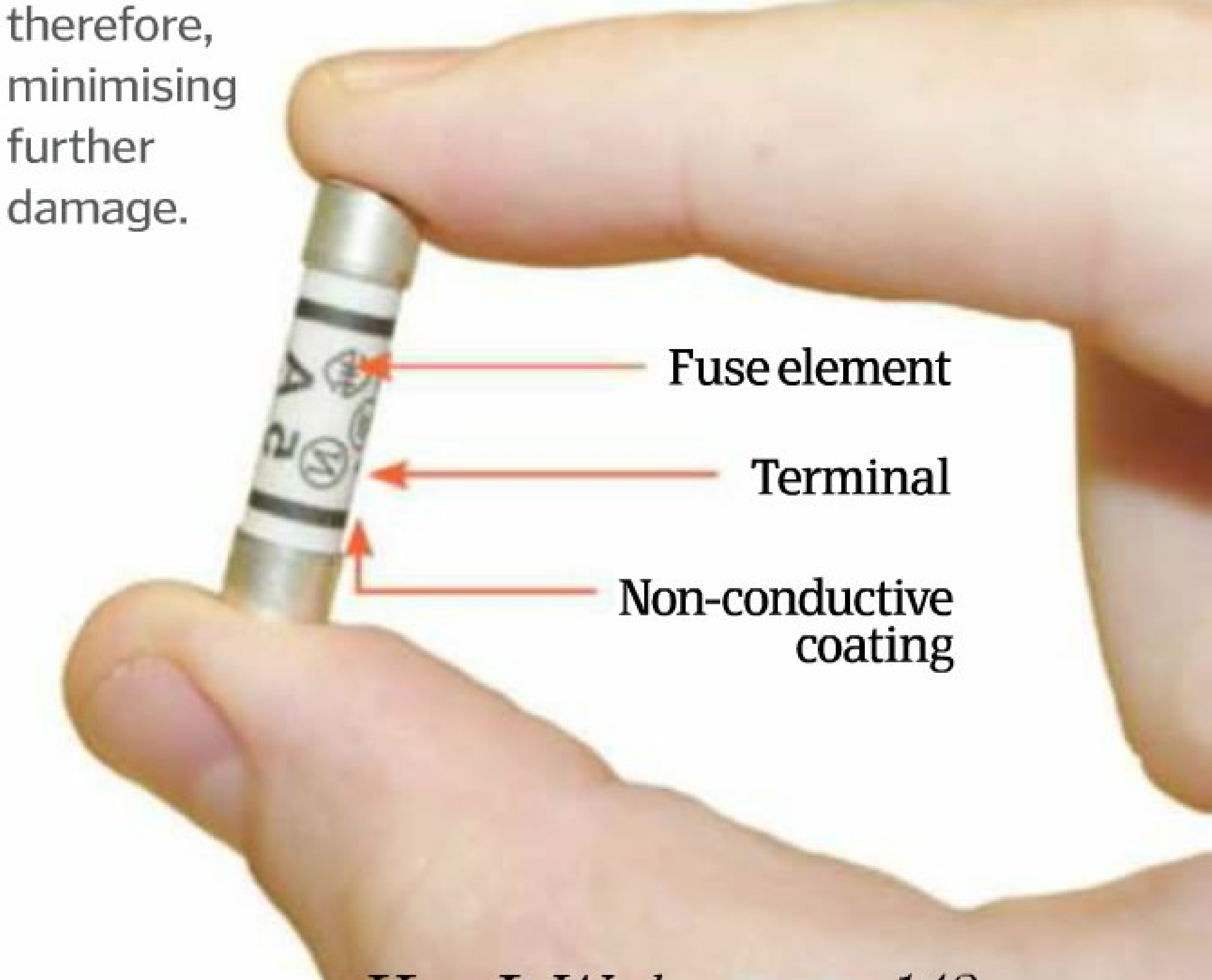
The computers can be plugged into the router using a network cable, but Wi-Fi is more convenient as it uses radio signals. The wireless device in the computer and router then work like two-way radios, sharing large amounts of information.

The router can use different radio channels, but the information packets are addressed to a specific machine. To ensure the communications stay safe, there are different ways to encrypt it, and that's why you need to set up a password.

How do fuses work?

Fuses are essentially fire breaks, points of deliberate weakness that, if the power surges through a house's electrical system, will collapse to prevent damage or fire. This is achieved by the fuse's central component, a strip or strand of metal which has a lower breaking capacity. The metal's breaking capacity is the maximum current that can be passed through it safely, while anything above that will cause it to melt and break the circuit. Zinc, copper, silver and aluminium are all commonly used as fuse wire.

The fuse wire is placed between two terminals, wrapped in a non-conductive material and put in place. If a power surge happens, the fuse will break, severing the connection, closing the circuit and, therefore, minimising further damage.



146......How is car safety tested?
150......What is a camshaft?
150......What are air brakes?
151.......How does a handbrake stop a vehicle?
151.......How do tyre valves work?
152......Do turbochargers boost performance?
154......How do carwashes clean cars?
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Transport

> “These rail systems work by simply dropping the missile on command from the mount”

How is car safety tested?

Take a look behind the scenes at the extreme measures taken to ensure car safety

At the turn of the 20th Century, and with the rising popularity of the automobile, the internal combustion engine pulled itself into a position of dominance over steam and electric. By the Fifties cars were a common sight – and so were car-related accidents.

Though crash testing had begun with General Motors' 1934 barrier test, car safety features of the time, such as padded dashboards and recessed controls, were considered a luxury. For owners of popular Fifties models like the 1959 Chevrolet Bel Air, you could expect a stylish set of wheels that looked like nothing else on the road. Woe betide anyone who had an accident in it though: with no seatbelts or other safety features, all occupants were left at the mercy of fate. For most car manufacturers, safety took the proverbial back seat, so crumple zones and other energy-absorbing features mandatory in the design of today's cars simply didn't exist. A 64-kilometre (40-mile)-per-hour, head-on collision would often see the Bel Air's body crumple, the driver-side door fly open and the steering column punch into the driver as the front end concertinaed.

As a result of the increasing number of cars on the road, the last half-century has seen car safety take a higher priority in the automobile industry. It's primarily been driven by legislative measures to decrease road traffic collision fatalities, rather than particular demand by consumers. Because history has shown that although we are becoming more safety conscious, we tend to buy fast, powerful, stylish, cheap and practical before safe. After all, we're planning on using our cars to take us to work, pick the kids up from school or go for day trips, and ploughing into another vehicle doesn't really factor in to our itinerary.

NCAP (the New Car Assessment Program) and Euro NCAP are the government-backed car safety evaluation schemes for the US and Europe, respectively. The Ford test centre in Merkenich, Germany, includes a 100-metre (329-foot) runway along which a sled on wheels, representing an oncoming vehicle, is propelled into the test car and then photographed with a high-speed camera at 1,000 frames per second, for experts to later examine. NCAP tests for a variety of low to medium-speed collisions, including a potentially deadly car-to-car, side-impact collision at 50 kilometres (31 miles) per hour that the new Ford B-Max – one of the safest cars in the world currently – excelled at.

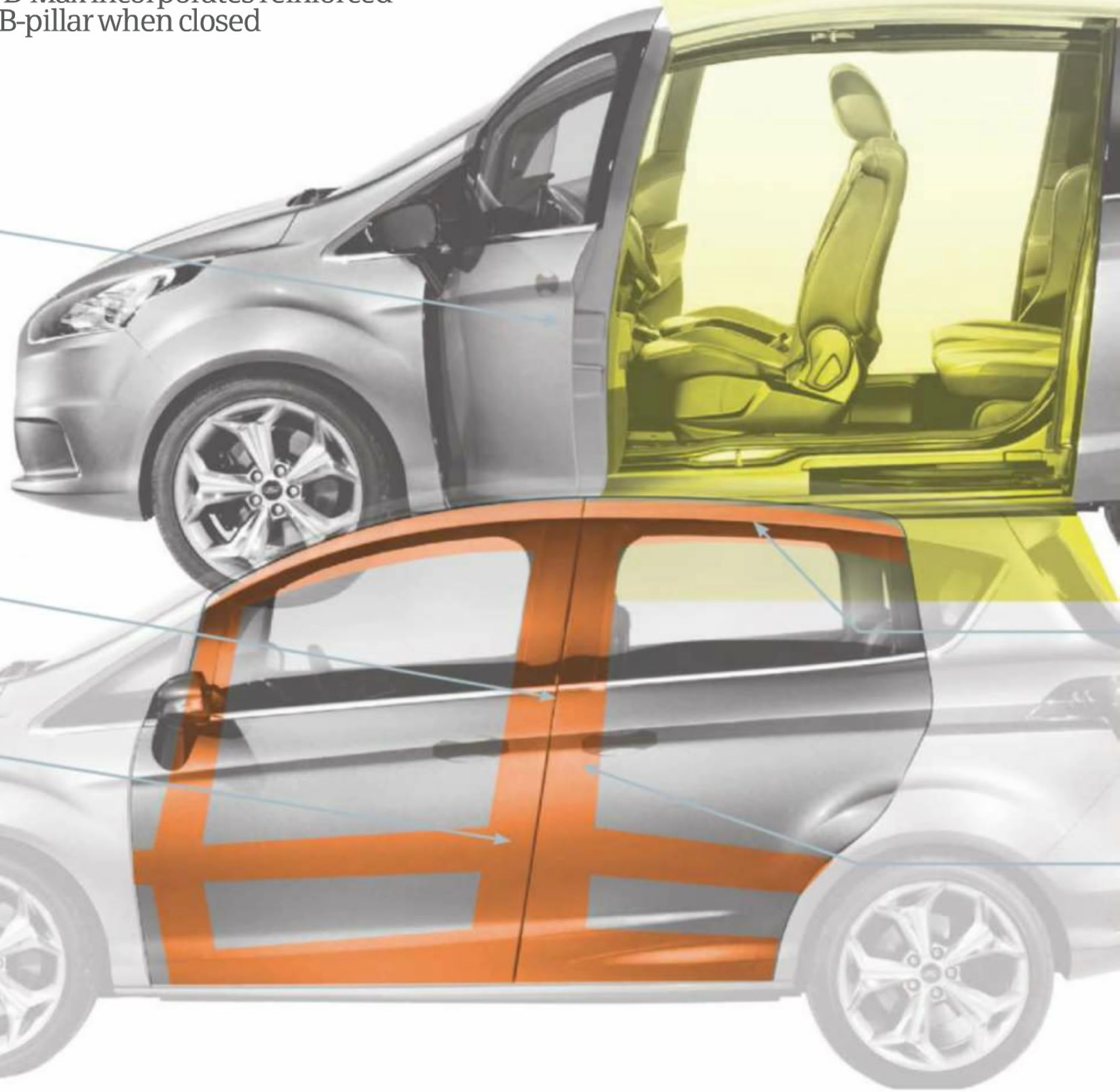
Centres like this run tests on whiplash, seatbelt protection assessment and stressing the computer-controlled safety measures common in modern cars, such as electronic stability control. It's not all about the occupants either; Euro NCAP has made its pedestrian safety score an integral part of its rating. This is based on the protection a car affords to the most vulnerable areas of a pedestrian – the legs and head – on being struck at 40 kilometres (25 miles) per hour.

“As a result of the increasing number of cars on the road, the last half-century has seen car safety take a higher priority”

The Ford B-Max is expected to score highly on the Euro NCAP and so become one of the safest cars on the market

An innovative idea

Ford's aim in designing the B-Max model was to create a vehicle with no B-pillar - the central column that divides passenger and front seats - for increased accessibility. Without any support in this area however, the vehicle is structurally weak, so the B-Max incorporates reinforced doors that lock to form a B-pillar when closed



Portal
Normal doors on a vehicle with an opening like this would be catastrophic for the occupants in a high-impact collision.

B-pillar
Both doors come together to form the B-pillar, a vital component in car occupant safety.

Locks
Ultra-high strength steel brackets (dubbed 'crash catchers') lock the doors tight together when another vehicle hits impacts the side.

The road to car safety

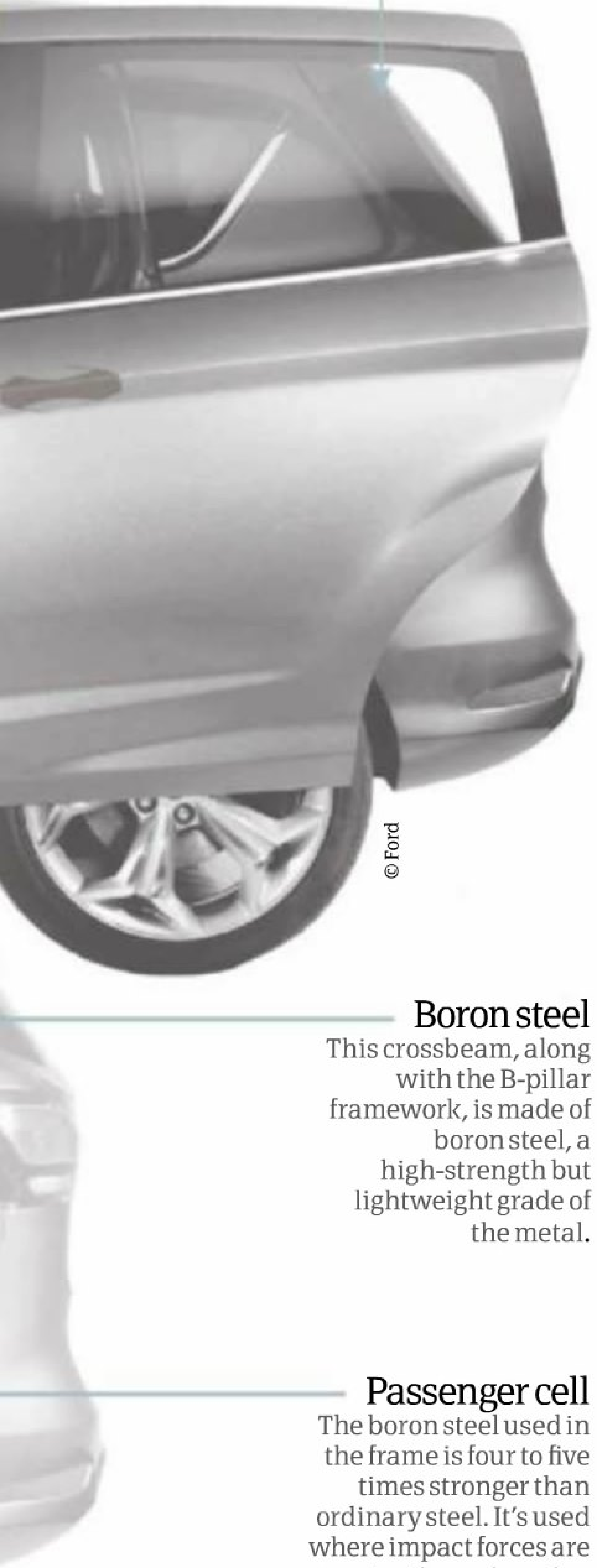
We've been driving for over a century but, until the Fifties, car safety took a back seat. But that's changed radically over the last 60 years…

1958
Volvo invents the most enduring and beneficial car safety feature ever, with Nils Bohlin patenting and refining the three-point car seatbelt.

1966
Luxury hand-built sports car Jensen FF includes the first mechanical anti-lock braking system (ABS). The system is now used as standard on most cars.

1979
The NHTSA establishes the New Car Assessment Program, with the goal of encouraging car manufacturers to make safer cars and getting the public to buy them.

1981
German car manufacturer Mercedes becomes the first production car-maker to include a driver's airbag in its Mercedes-Benz S-Class model.



Sliding door
The rear door on the B-Max slides open only if the fuel cap, located at the rear, isn't open.

© Ford

Boron steel
This crossbeam, along with the B-pillar framework, is made of boron steel, a high-strength but lightweight grade of the metal.

Passenger cell
The boron steel used in the frame is four to five times stronger than ordinary steel. It's used where impact forces are greatest in conjunction with a passenger cell designed to reduce deformation in a crash.

How car safety rating works

Take a closer look at the four main criteria on which Euro NCAP bases its safety scores

The Euro New Car Assessment Programme (Euro NCAP) scores new vehicles in four key areas: adult protection, child protection, pedestrian protection and safety assist (driver assistance and active safety technologies). The system has naturally evolved over the years with the introduction of new tech, first awarding additional points for cars incorporating them into the design, then making the new safety measures a standard part of the NCAP rating.

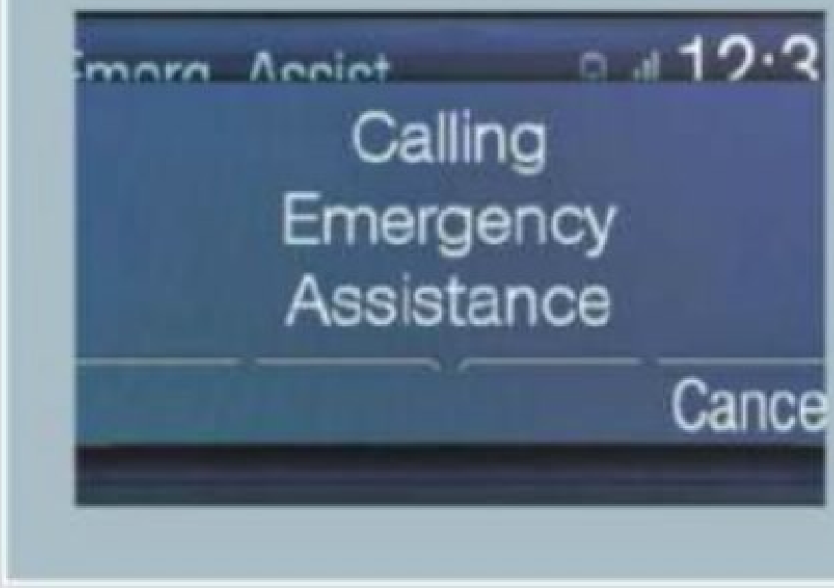
Adult occupant and pedestrian protection formed the original rating system when Euro NCAP was founded back in 1997, the child occupant safety rating was introduced in 2003, while safety assist only came along in 2009 with the rise of electronic safety systems. These days, new cars are tested for whiplash protection and NCAP also rewards vehicles that are installed with speed-limitation devices and electronic stability control (ESC).

Euro NCAP calculates the final rating for each vehicle by weighing up the results of these four tests, ensuring each area meets its stringent standards and then scoring out of five stars.

Emergency computer calls

The B-Max includes an interesting active safety feature called Emergency Assist. Once the system has been Bluetooth-paired with a smartphone, it places a call with a local 112 emergency operator (112 being the emergency number everywhere in the EU) if either the airbag or emergency fuel shutoff is deployed within the car.

Using the on-board GPS locator, it informs the emergency services of your location – though if it's activated by accident, there's a ten-second window in which the occupants of the B-Max can cancel the call. Emergency Assist is potentially life-saving technology and, as a result, it's looked on favourably by Euro NCAP testers.



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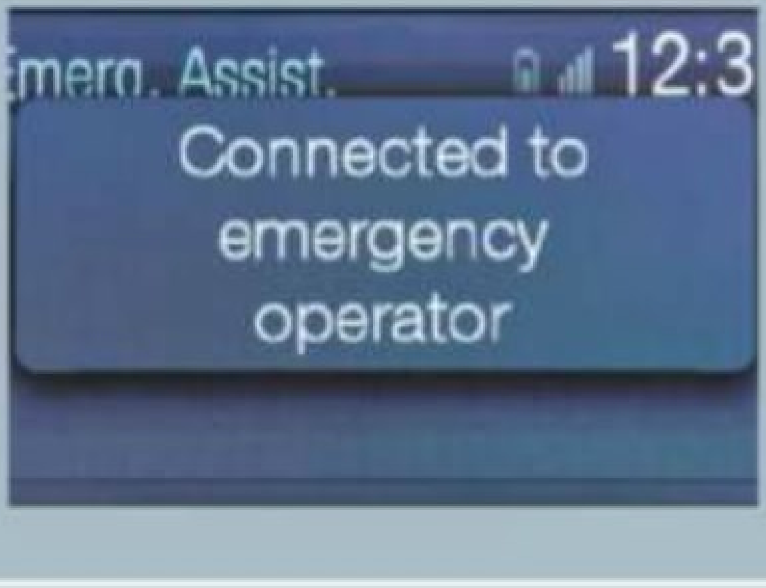
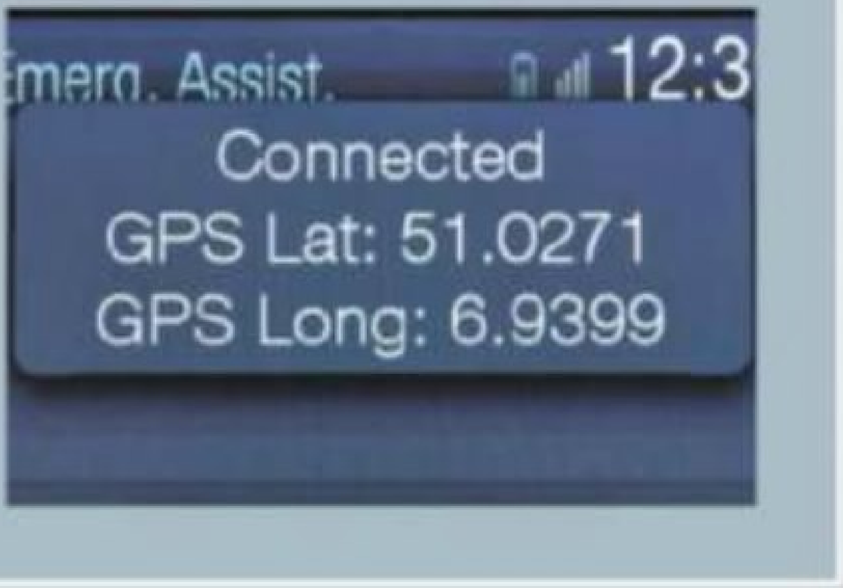
Calling Emergency Assistance

Cance



merg. Assist. 12:3

Connected to emergency operator



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Connected

GPS Lat: 51.0271

GPS Long: 6.9399

1983
Wearing front seatbelts becomes law in the United Kingdom. A fine of up to £500 is applicable if the person responsible is convicted in court.

1997
The EC supports the Euro NCAP initiative and, in 1997, Euro NCAP releases its first results. Notably, the Rover 100 scores one out of a possible five stars.

2001
The Renault Laguna is the first Euro NCAP car to receive five out of five stars for occupant protection. Since then, car safety standards have risen.

2007
After several high-profile incidents involving pedestrians seriously hurt by 4x4 vehicles with front-mounted metal bull bars, fitting bull bars to a road vehicle becomes illegal in the UK.

2008
In response to the ever-increasing number of whiplash injury claims, Euro NCAP introduces a new whiplash prevention test.

2009
With pedestrian safety being neglected, Euro NCAP makes sure this element of road user safety is a key part of its new safety rating system.

What is a camshaft?

The smooth running of an engine is dependent on a camshaft which precisely manages the flow of energy that enters and leaves

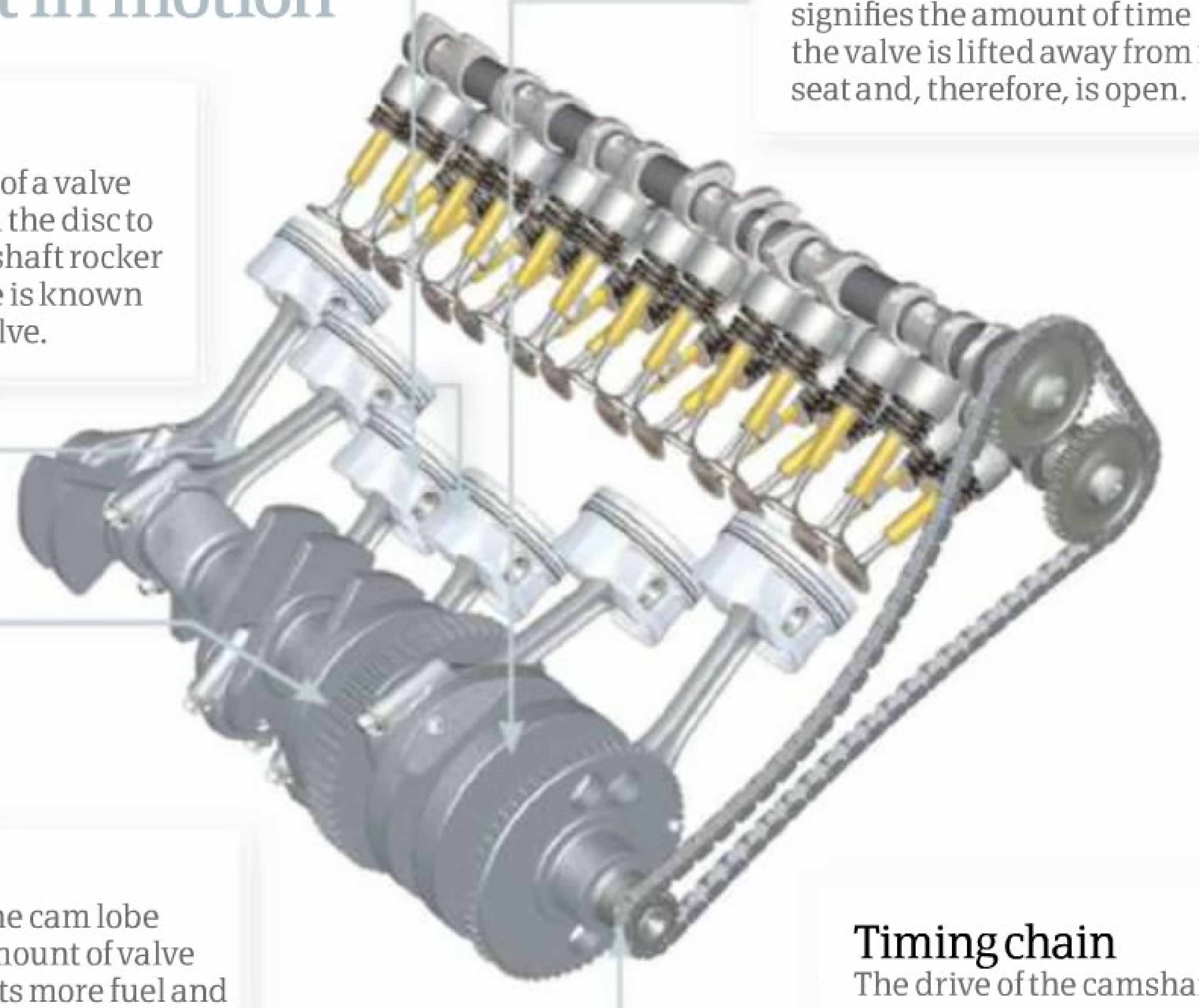
The flow of fuel and air through an engine is controlled by the opening and closing of valves. The timing of this is crucial and is dictated by an object known as a camshaft. The technology behind the camshaft has been used for hundreds of years in a range of different devices, including water clocks, and it is the rotation of this important engine part that forces the valves open and shut at regular intervals.

A camshaft is mounted at the top of the engine. Along its length are lobes, which push on rocker arms as it rotates. At the other end of these are valves, which move up and down as the rocker arms push on them, opening and closing as they move.

The rotation and timing of a camshaft is in turn controlled by the rotation of the crankshaft, which is the main drive section at the bottom of the engine. A timing chain or belt stretches from the crank to the cam, so that the two move in unison.

Many cars have two sets of inlet and exhaust valves to get more air and fuel in and out of the engine. This requires double overhead cams; the main timing belt drives one cam, with a short intermediate chain connecting the second.

Camshaft in motion



Overlap
Overlap is where two valves are open at the same time, a vital part of a cam's design. The balance is crucial to an engine's smooth running and performance output.

Duration
Cam timing is measured in degrees; the duration signifies the amount of time the valve is lifted away from its seat and, therefore, is open.

Valve
The long stem of a valve stretches from the disc to meet the camshaft rocker arm. This type is known as a poppet valve.

Lift
The shape of the cam lobe controls the amount of valve lift. More lift lets more fuel and air flow in, which is a must for performance engines.

Timing chain
The drive of the camshaft is governed by the crank. Drive is transferred via the timing chain.

* * *

What are air brakes?

Air brakes can quickly stop mighty loads

Air brakes work differently to those on vehicles, creating a system where the brakes are always on when in a neutral state. As such, rather than using compressed air to activate a vehicle's brakes, it is used instead to deactivate them. This is a design feature very much aimed to maximise safety, because if the air brake system fails then the vehicle will be forced to automatically stop moving.

A compressed air brake array is divided into a supply system and control system. The supply system draws air into a compressor from the surrounding environment, filters it, stores it inside a reservoir and then distributes it to the control system. The control system consists of a brake circuit and trailer brake circuit, which are split into front and rear wheel circuits. These individual circuits receive air from the supply system's reservoir.

As such, the brakes of heavy-duty road vehicles are essentially engaged on a permanent basis, requiring the driver to disengage them to accelerate – ie the brake circuits' release valves are opened, dropping the contained air pressure and releasing the physical brake components (ie the callipers and brake pads) from the wheels, leaving the vehicle free to move.

© Panoha

Distribution
Air is stored in a reservoir from which it's distributed via a four-way protection valve into the front/rear brake circuits.

Drive
The air compressor is driven off the truck's engine either by crankshaft pulley via a belt or directly off its timing bars.

Filter
Compressed air is drawn in and then routed through a cooling coil and air dryer to remove moisture and any impurities in the oil.

How does a handbrake stop a vehicle?

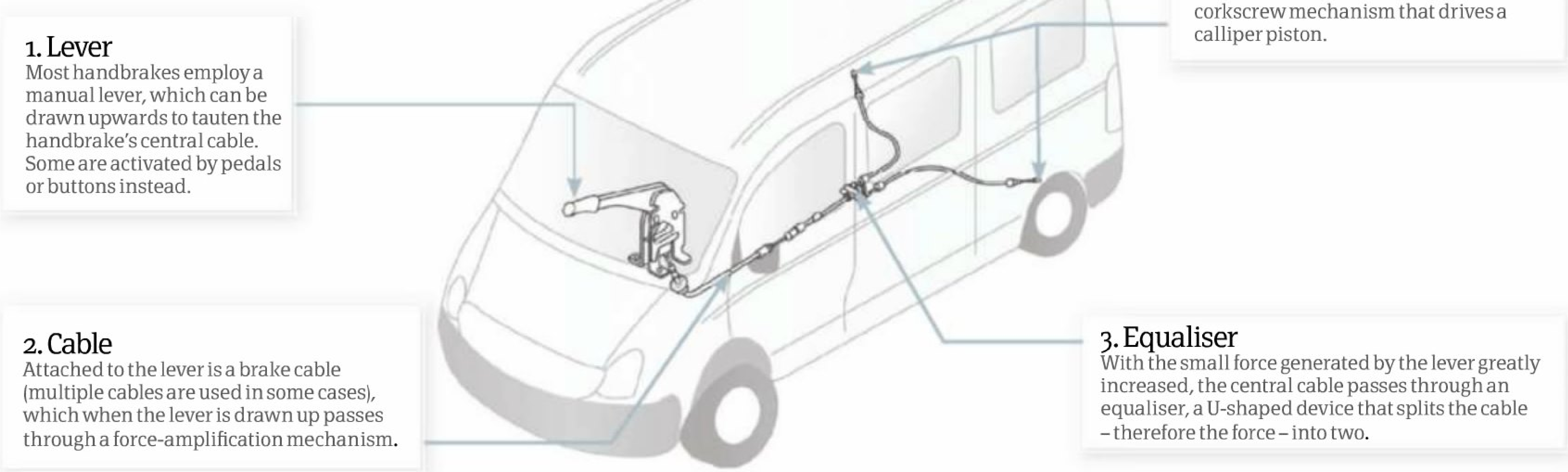
A closer look at the safety feature that can stop a car

A handbrake is an additional braking mechanism, which is installed on all commercial vehicles by default, that is completely separate from the main foot pedal-operated brakes. The role of the handbrake is to both supply an emergency means of stopping if the primary brakes fail – if the brake fluid leaks, for example – and also as a tool to assist with parking the vehicle. The latter role is especially useful if a driver needs to park their vehicle on a steep incline, as it provides a degree of safety.

Critically, handbrakes are purely mechanical braking tools, relying on a series of levers, cables and screws to activate a car's wheel brakes. In being designed this way, they offer a greater level of safety and reliability than the more complex, if more powerful, hydraulic types. Essentially, being simpler, there is less that can go wrong with them so they are less likely to fail before the main brakes. As shown in the diagram below, the handbrake system originates at the front of the vehicle – typically perceived by the user as a lever – and culminates at the rear wheels where the brakes engage to stop a car in its tracks.

A handbrake in action

See how your vehicle's handbrake works



1. Lever
Most handbrakes employ a manual lever, which can be drawn upwards to tauten the handbrake's central cable. Some are activated by pedals or buttons instead.

2. Cable
Attached to the lever is a brake cable (multiple cables are used in some cases), which when the lever is drawn up passes through a force-amplification mechanism.

3. Equaliser
With the small force generated by the lever greatly increased, the central cable passes through an equaliser, a U-shaped device that splits the cable – therefore the force – into two.

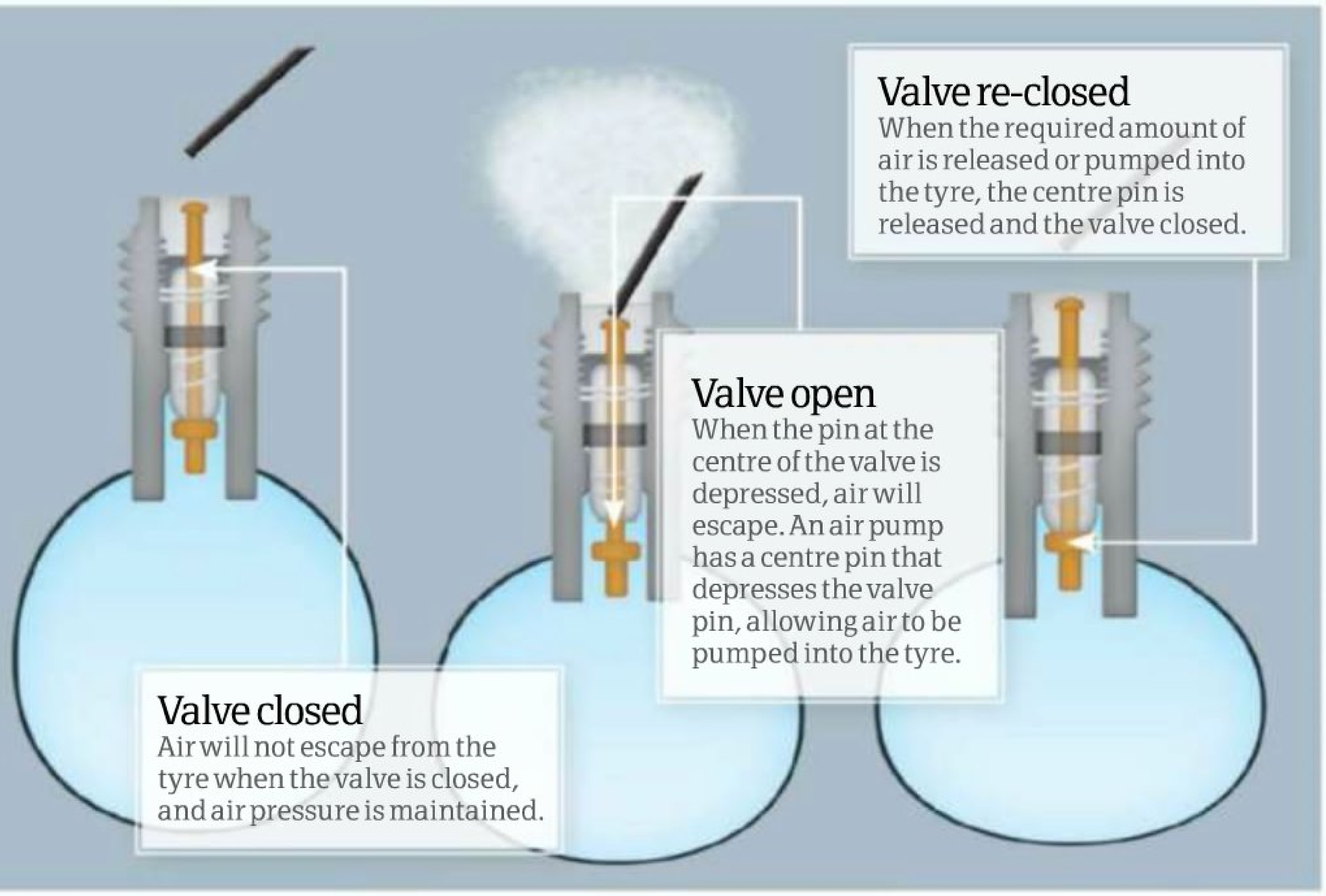
4. Brakes
With drum brakes the split cables go directly to the rear wheels' brake shoes; while with disc brakes, they go to a corkscrew mechanism that drives a calliper piston.

How do tyre valves work?

Keeping air under pressure inside tyres

All tyres use a form of poppet valve, with the most common being the Schrader valve. This consists of a hollow cylindrical stem that has threading outside it. Running through the centre of the stem is a spring-loaded pin inside a sleeve.

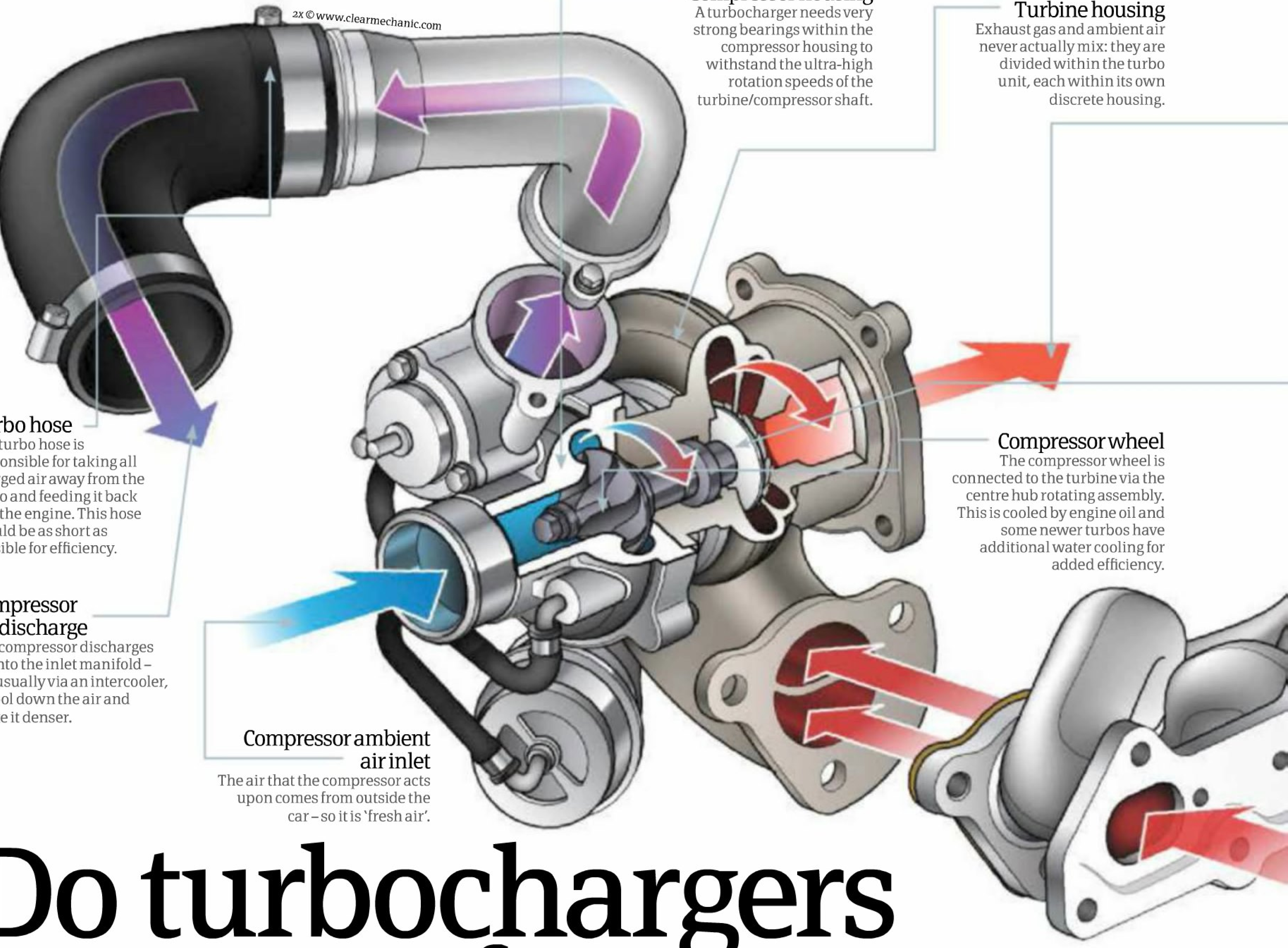
A small disc that is located at the bottom of the pin prevents any air from escaping through the sleeve, and when the pin is then pushed down, air is then able to escape through the valve. The strength of the spring determines the pressure that is needed to push it open.



Valve closed
Air will not escape from the tyre when the valve is closed, and air pressure is maintained.

Valve open
When the pin at the centre of the valve is depressed, air will escape. An air pump has a centre pin that depresses the valve pin, allowing air to be pumped into the tyre.

Valve re-closed
When the required amount of air is released or pumped into the tyre, the centre pin is released and the valve closed.



2x © www.clearmechanic.com

Compressor housing
A turbocharger needs very strong bearings within the compressor housing to withstand the ultra-high rotation speeds of the turbine/compressor shaft.

Turbine housing
Exhaust gas and ambient air never actually mix: they are divided within the turbo unit, each within its own discrete housing.

Turbo hose
The turbo hose is responsible for taking all charged air away from the turbo and feeding it back into the engine. This hose should be as short as possible for efficiency.

Compressor wheel
The compressor wheel is connected to the turbine via the centre hub rotating assembly. This is cooled by engine oil and some newer turbos have additional water cooling for added efficiency.

Compressor air discharge
The compressor discharges air into the inlet manifold – but usually via an intercooler, to cool down the air and make it denser.

Compressor ambient air inlet
The air that the compressor acts upon comes from outside the car – so it is 'fresh air'.

Do turbochargers boost performance?

Turbochargers use waste exhaust to help cars generate more power: they really do give something for nothing…

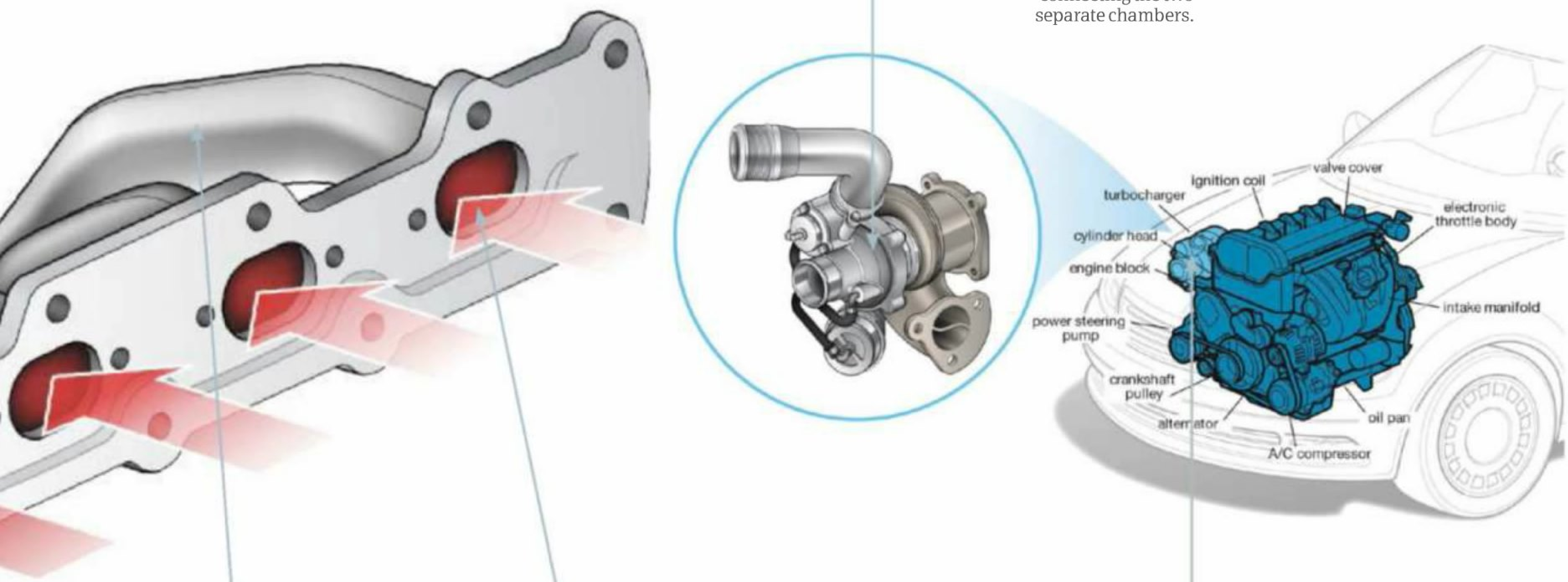
A turbocharger is a great example of getting something from nothing. These devices use waste gases from engine combustion, which are normally expelled into the atmosphere through the exhaust pipe, to produce even more engine power: they are essentially a 'free' performance boost and can be fitted to almost any engine in order to make it operate more efficiently.

They help make a smaller-capacity engine generate the power of a larger one, without suffering the fuel economy penalties associated with big-block engines. They also mean that smaller vehicles can have much higher outputs despite the restricted space that is afforded by their engine bays, which allows manufacturers to make lighter, faster vehicles.

A turbocharger works by using the kinetic energy from the exhaust gas airflow to spin a turbine, which is connected to an air pump that compresses air via a compressor wheel. The process itself is called forced induction, and the air is compressed in order to significantly increase its pressure, density and temperature. Alternatively, an engine without a turbocharger (an increasing rarity these days) is considered to be naturally aspirated.

Compressed, higher-density air contains more oxygen, which thus improves combustion and – when mixed with extra fuel – this ultimately produces more power. Each 'bang' of the engine's combustion cycle is bigger and more potent; as a result, smaller cylinders – and less of them – can be used to generate the same cumulative power as engines with more and larger cylinders which are naturally aspirated.

> “They help make a smaller-capacity engine generate the power of a larger one”



Turbine exhaust gas discharge
Once it has spun the turbine, the exhaust gas is free to carry on through the exhaust pipe to exit into the atmosphere.

Turbine wheel
Turbine response can be improved with a twin-scroll design – this has two exhaust gas inlets into the turbine: one optimised for low-speed flow and the other for high-speed flow.

Basic layout
There are three main sections to a turbocharger unit: the turbine, the compressor and the centre hub rotating assembly connecting the two separate chambers.

Exhaust manifold
The exhaust manifold is directly connected to the turbo. Engine designers focus on making this gap as short as possible.

Exhaust gas from combustion chamber
All air used by the motor during combustion leaves through the exhaust manifold: this means everything the engine produces is available to charge the turbo.

Turbocharger
To ensure the pressure produced by the turbo does not get too high, a wastegate regulator is usually integrated into the unit, allowing exhaust gases to bypass the turbine.

Since a turbocharger works by using waste exhaust gases, the turbine gets very hot. This heats up the compressor and that, in turn, further heats up the compressed air too. Because cool air is needed to attain maximum engine efficiency, most turbocharged engines have an intercooler, through which the hot air passes and is cooled before it reaches the engine.

Today, turbochargers are used by nearly every diesel engine on the market for one very good reason: they increase the power of an inherently less efficient type of engine without negating the impressive fuel economy for which many people choose to buy diesel engines in the first place. More and more petrol cars are beginning to use turbochargers too, as car manufacturers ‘downsize’ their engines – replacing bigger, less green motors with smaller, more efficient engines that offer the same power.

A turbocharger’s power is not quite completely free though – the additional back pressure in exhaust due to the turbine does cost a vehicle a little horsepower, but this is minimal compared to the mighty gains that it brings.

How do carwashes clean cars?

Washing a car takes time, effort and lots of water, so how do drive-throughs simplify the process?

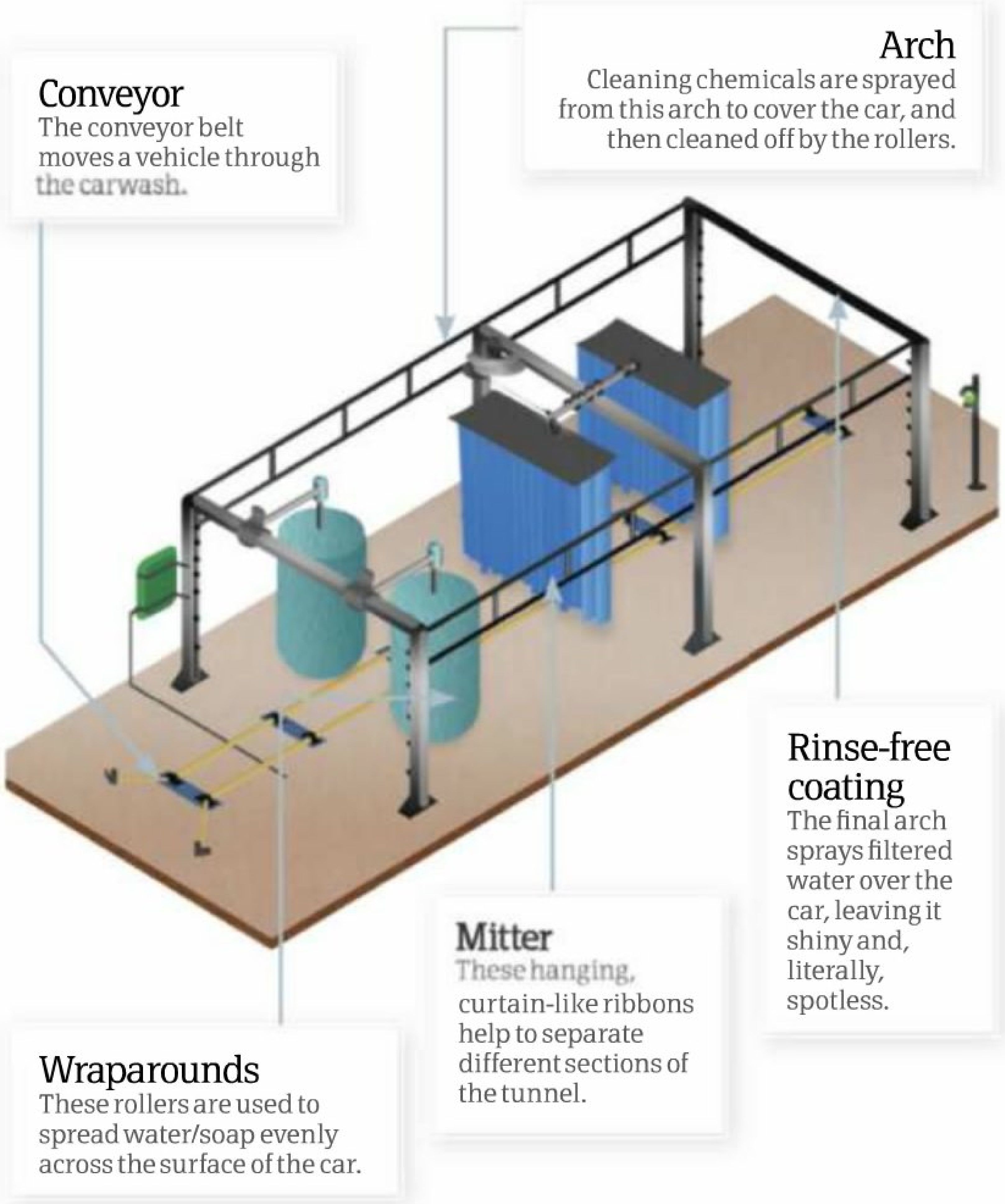
An automatic carwash is the fastest and most efficient way to get a car clean. On arrival, drivers choose a programme, typically from an automatic terminal, and position their cars on a central conveyor belt, which will carry them through the washing tunnel.

The wash cycle begins with arches that spray pre-soak chemicals onto the car's bodywork. Chemical tyre applicators aimed at the wheel arches spray more detergents to tackle these generally dirtier areas. Following this, large cylindrical rollers – which are known as wraparounds – rub the bumpers and sides of the car. At the same time, many carwashes will deploy a tyre brush to clean the wheels further; this is often located behind a mitter, a curtain of hanging, ribbon-like cloth.

Beyond that is often another set of wraparounds. High-pressure water hoses can be installed here to clean difficult-to-reach areas of the vehicle and floor-mounted undercarriage systems are also a common feature on many carwashes. A last set of rollers continues to lift the water, dirt and chemical solution and finally the car is treated with a drying agent and a 'spot-free' coat of filtered water with no salts, ensuring no residue is left on the bodywork.

Drive-throughs revealed

How do they get your car looking as good as new?


Conveyor
The conveyor belt moves a vehicle through the carwash.
Arch
Cleaning chemicals are sprayed from this arch to cover the car, and then cleaned off by the rollers.
Rinse-free coating
The final arch sprays filtered water over the car, leaving it shiny and, literally, spotless.
Mitter
These hanging, curtain-like ribbons help to separate different sections of the tunnel.
Wraparounds
These rollers are used to spread water/soap evenly across the surface of the car.

Multi-grade oils have a base viscosity grade when cold, and a second grade for when hot

What is engine oil?

The lubricant that most vehicles can't function without

Engine oil – or motor oil as it's also known – is designed to lubricate the inner components of internal combustion engines, as well as to protect them against corrosion and keep them cool while in use.

It's made from two main elements: base stock and additives. The base stock commonly makes up approximately 95 per cent of the solution and is either made from petroleum, synthetic chemicals or a mixture of the two. The base stock is responsible for lubricating an engine's moving parts and removing built-up heat.

The additives, meanwhile, account for roughly five per cent of the oil and it is these chemicals that are responsible for finely controlling oil viscosity and lubricity, as well as protecting the numerous engine parts against wear and tear. For example, zinc dialkyldithiophosphate (ZDDP) is a frequently used additive for preventing engine wear, while magnesium sulphonates help the oil to break down impurities and engine sludge.

Engine oils are rated by both their grade and viscosity. Any oil can either be single-grade, with a set viscosity level, or multi-grade in which the oil can act at two different viscosities depending on its current temperature.

The latter is most prevalent today, to cater for vehicles used all year round in various different weather conditions. The flow-rate of both single- and multi-grade oils is measured on a viscosity grade scale, which includes 11 grades ranging from 0 to 60. Lower-ranked oils are thicker than higher-ranked ones, making them more suitable to cold environments, and vice versa.

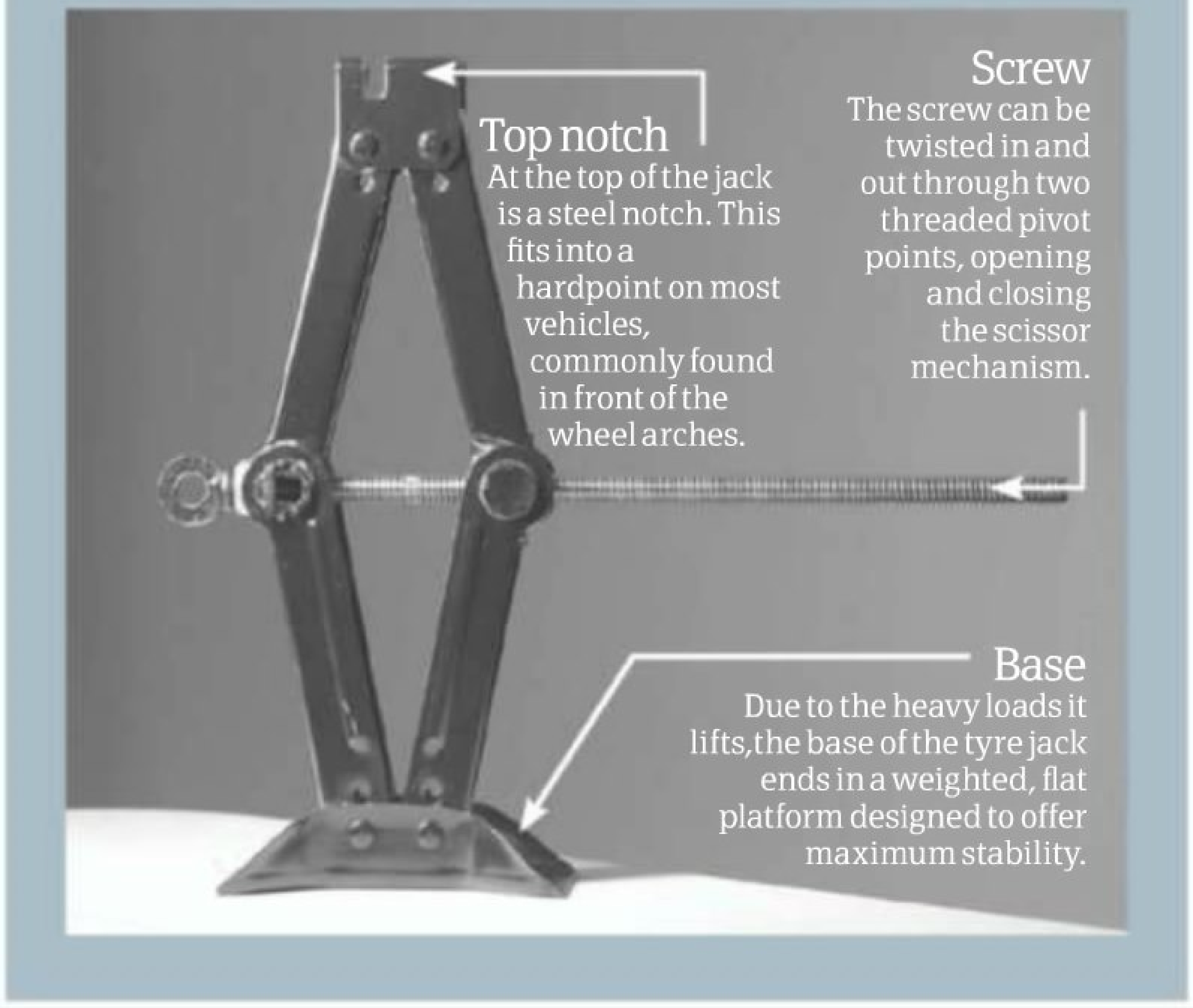
> "The base stock is responsible for lubricating an engine's moving parts"

How do scissor jacks lift cars?

How these devices prop up heavy vehicles

There are two main kinds of car jack: those operated by screw and those operated by hydraulics. For standard road vehicles, the screw type is most common, often coming in the form of a scissor jack. These work by using a two-piece mechanism in partnership with a self-locking central screw. Combined, these elements enable a vehicle to be lifted through the extension of the scissor mechanism, while being held in place by the resistive force of the screw.

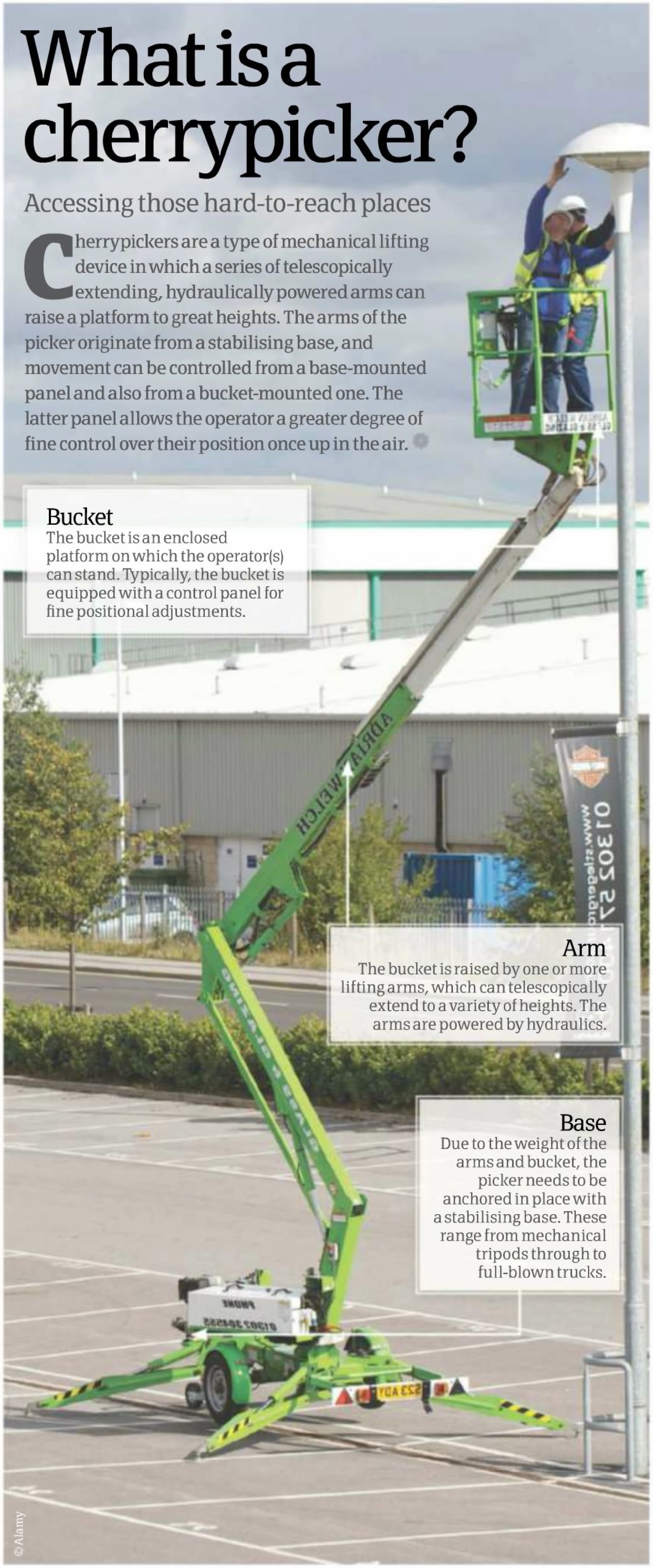
The central screw is also how the jack is operated, with an end-mounted circular ring designed to accept a large Allen key-shaped metal arm. When inserted and turned clockwise this arm drives the screw through the mechanism's central pivot points' thread, elongating the jack and raising the vehicle. In contrast, rotating counter-clockwise unthreads the screw, lowering the car.



Top notch
At the top of the jack is a steel notch. This fits into a hardpoint on most vehicles, commonly found in front of the wheel arches.

Screw
The screw can be twisted in and out through two threaded pivot points, opening and closing the scissor mechanism.

Base
Due to the heavy loads it lifts, the base of the tyre jack ends in a weighted, flat platform designed to offer maximum stability.



What is a cherrypicker?

Accessing those hard-to-reach places

Cherrypickers are a type of mechanical lifting device in which a series of telescopically extending, hydraulically powered arms can raise a platform to great heights. The arms of the picker originate from a stabilising base, and movement can be controlled from a base-mounted panel and also from a bucket-mounted one. The latter panel allows the operator a greater degree of fine control over their position once up in the air.

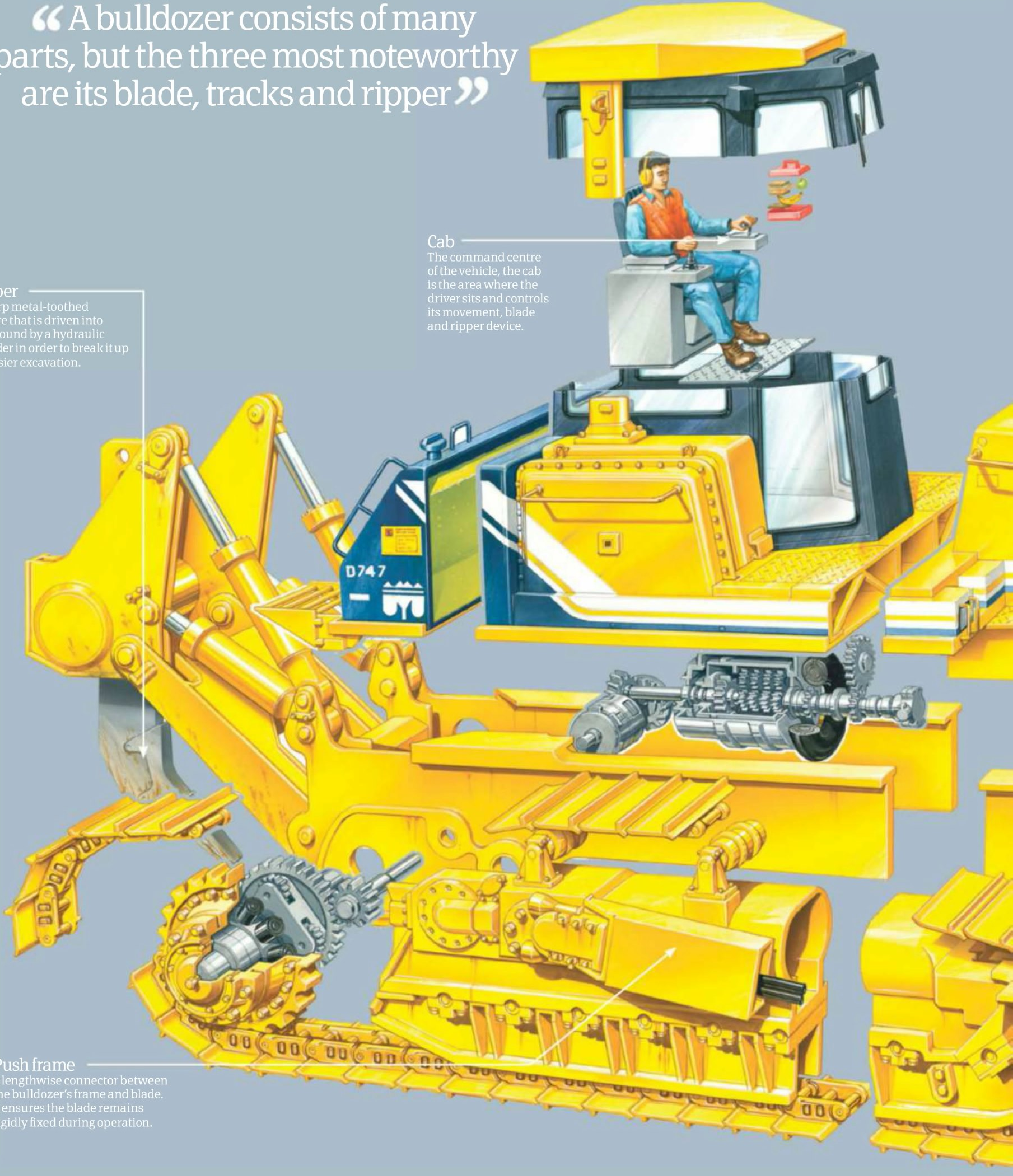
Bucket
The bucket is an enclosed platform on which the operator(s) can stand. Typically, the bucket is equipped with a control panel for fine positional adjustments.

Arm
The bucket is raised by one or more lifting arms, which can telescopically extend to a variety of heights. The arms are powered by hydraulics.

Base
Due to the weight of the arms and bucket, the picker needs to be anchored in place with a stabilising base. These range from mechanical tripods through to full-blown trucks.

© Alamy

> “A bulldozer consists of many parts, but the three most noteworthy are its blade, tracks and ripper”



Cab
The command centre of the vehicle, the cab is the area where the driver sits and controls its movement, blade and ripper device.

Ripper
A sharp metal-toothed feature that is driven into the ground by a hydraulic cylinder in order to break it up for easier excavation.

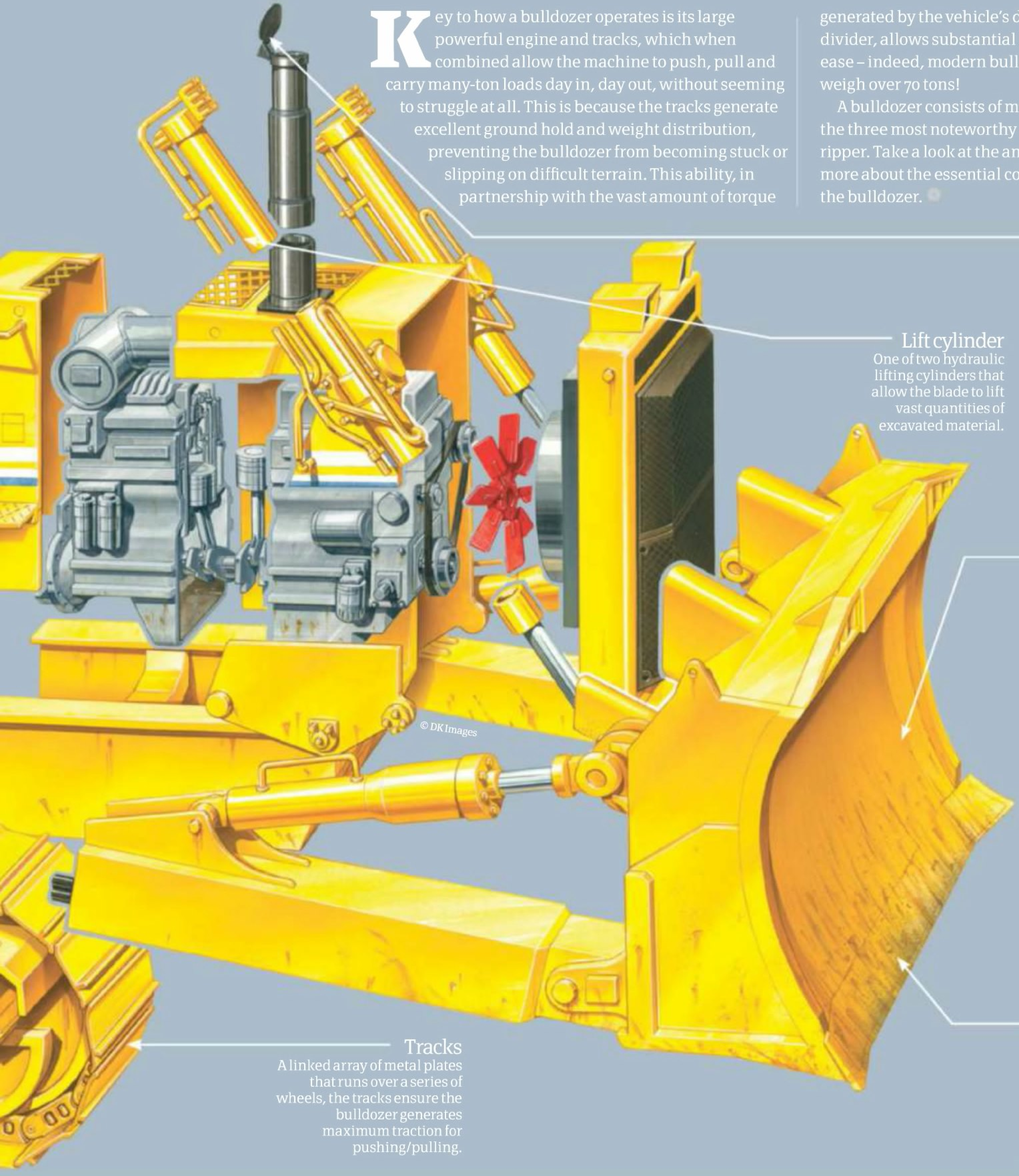
Push frame
A lengthwise connector between the bulldozer's frame and blade. It ensures the blade remains rigidly fixed during operation.

What's inside a bulldozer?

Designed to demolish all in their path, discover what makes them so powerful

Key to how a bulldozer operates is its large powerful engine and tracks, which when combined allow the machine to push, pull and carry many-ton loads day in, day out, without seeming to struggle at all. This is because the tracks generate excellent ground hold and weight distribution, preventing the bulldozer from becoming stuck or slipping on difficult terrain. This ability, in partnership with the vast amount of torque generated by the vehicle's diesel engine and torque divider, allows substantial loads to be manipulated with ease – indeed, modern bulldozers can pull tanks that weigh over 70 tons!

A bulldozer consists of many different parts, but the three most noteworthy are its blade, tracks and ripper. Take a look at the animated image here to learn more about the essential components that make up the bulldozer.



© DK Images

Exhaust pipe
A large exhaust pipe through which the bulldozer's diesel engine can expel combustion gases.

Lift cylinder
One of two hydraulic lifting cylinders that allow the blade to lift vast quantities of excavated material.

Blade
A concave metal shield used by the bulldozer to push, scoop and destroy any material in front of it. It's powered by twin hydraulic cylinders.

Cutting edge
The bottom part of the bulldozer's blade that makes frequent contact with the ground. Due to heavy wear, it's designed as a replaceable part.

Tracks
A linked array of metal plates that runs over a series of wheels, the tracks ensure the bulldozer generates maximum traction for pushing/pulling.

How do street sweepers keep roads clean?

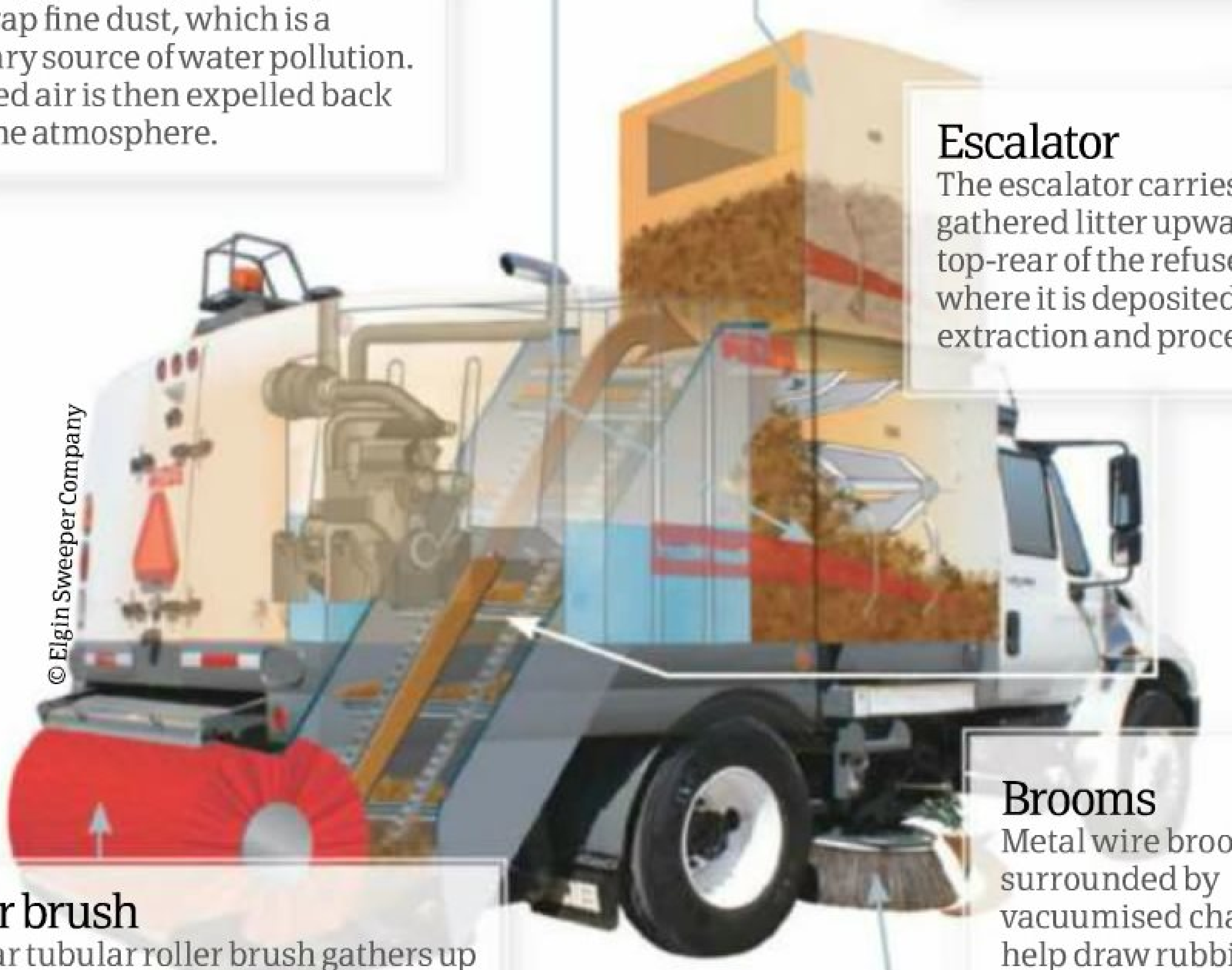
Discover how these vehicles pick up and process rubbish, with the aim of keeping our roads clean

Mechanical street sweepers today are usually large cab-over trucks equipped with a specialised cleaning module. The two main types of sweeper are characterised as wet and dry units, the former installed with a large water tank and sprayers to help loosen caked-in grime, and the latter relying solely on a set of rollers and brushes. Key to both variants, however, is a series of vacuumised chambers that surround the vehicles' litter collection units. These vacuums draw both rubbish and fine particulate matter into a refuse hold and filtering system, supporting the physical gatherers.

Once the rubbish is within the refuse hold, it is often exposed to a shaking unit, which separates further debris particles. These are sent, along with directly sucked-up dirt, into a filtering system. At this stage, a series of fans, filters and hoppers extracts the dust from the internal dirty air, traps and stores it for later disposal, and then expels the clean air.

The clean machine

Check out this cutaway to see how road sweepers gather and filter rubbish



© Elgin Sweeper Company

Filtering system
A series of fans, meshes, vibrators and hoppers designed to separate and trap fine dust, which is a primary source of water pollution. Filtered air is then expelled back into the atmosphere.

Refuse hold
The refuse hold is substantial and is equipped with a shaker to loosen particulate dust and debris from rubbish for processing by the sweeper's filtration system.

Escalator
The escalator carries the gathered litter upwards to the top-rear of the refuse hold, where it is deposited for later extraction and processing.

Roller brush
The rear tubular roller brush gathers up large-scale refuse and deposits it onto a central elevator. It is surrounded by a vacuumised chamber that sucks up finer particulate dirt.

Brooms
Metal wire brooms surrounded by vacuumised chambers help draw rubbish to the side of the sweeper into the mid-centre of the vehicle, where it's drawn up into the refuse hold.

* * *

© Joe Vinent

Design
The shallow depth to which the boats sink, coupled with their inflatable, lightweight top, make RIBs highly manoeuvrable so they lend themselves to rescue and safety scenarios.

Tough
The combination of a rigid hull and inflatable collar makes RIBs incredibly unlikely to sink, even after a collision with another boat.

Power
Most RIBs are powered either by an outboard motor or an inboard motor capable of up to 220kW (295hp).

Speed
A fairly regular six-seater RIB will usually be capable of a speed of about 30 knots (56km/h; 35mph). High-performance RIBs, however, can attain speeds of up to 70 knots (130km/h; 80mph).

Shape
The deeper the V-shape of the hull, the more easily the RIB will cut through waves (making for a more comfortable ride) at the cost of more power.

Can RIBs actually sink?

Discover how these versatile vessels combine a rigid frame with inflatable support to ensure they almost never sink

The rigid-hulled inflatable boat (RHIB), or rigid inflatable boat (RIB) for short, was first built in the Sixties, and has since proved highly versatile. The boats are characterised by their inflatable sections that sit atop a rigid hull, making them sturdy but also manoeuvrable.

Most RIBs are between four and nine metres (13 and 28 feet) in length, and are driven by either one or more outboard motors or a single inboard motor. The power of these boats can range from a tame four kilowatts (five horsepower) up to 220 kilowatts (295 horsepower). The hulls of RIBs are designed to hydroplane so that they glide across water.

The hulls are commonly made from steel, aluminium, wood or a combination of wood and glass-reinforced plastic (GRP, or fibreglass), while Kevlar is occasionally used for extra strength. The inflatable collar of a RIB consists of separate sections so that, in the event of a puncture, the vessel can still stay afloat. The tough material used is commonly Hypalon or PVC (polyvinyl chloride). There are also larger RIBs that have hard tops (cabins) for extra protection from the elements for both the crew and equipment.

How can you lift a boat into the air?

Discover how the Falkirk Wheel raises vessels 25 metres into the air

The Falkirk Wheel was part of an £84.5 million ($131.6 million) Millennium Link project to enable boats to travel between the Forth & Clyde Canal and the Union Canal in Falkirk, Scotland. At the site of a former open-cast mine, this feat of engineering replaced 11 locks that went out of use in the Thirties.

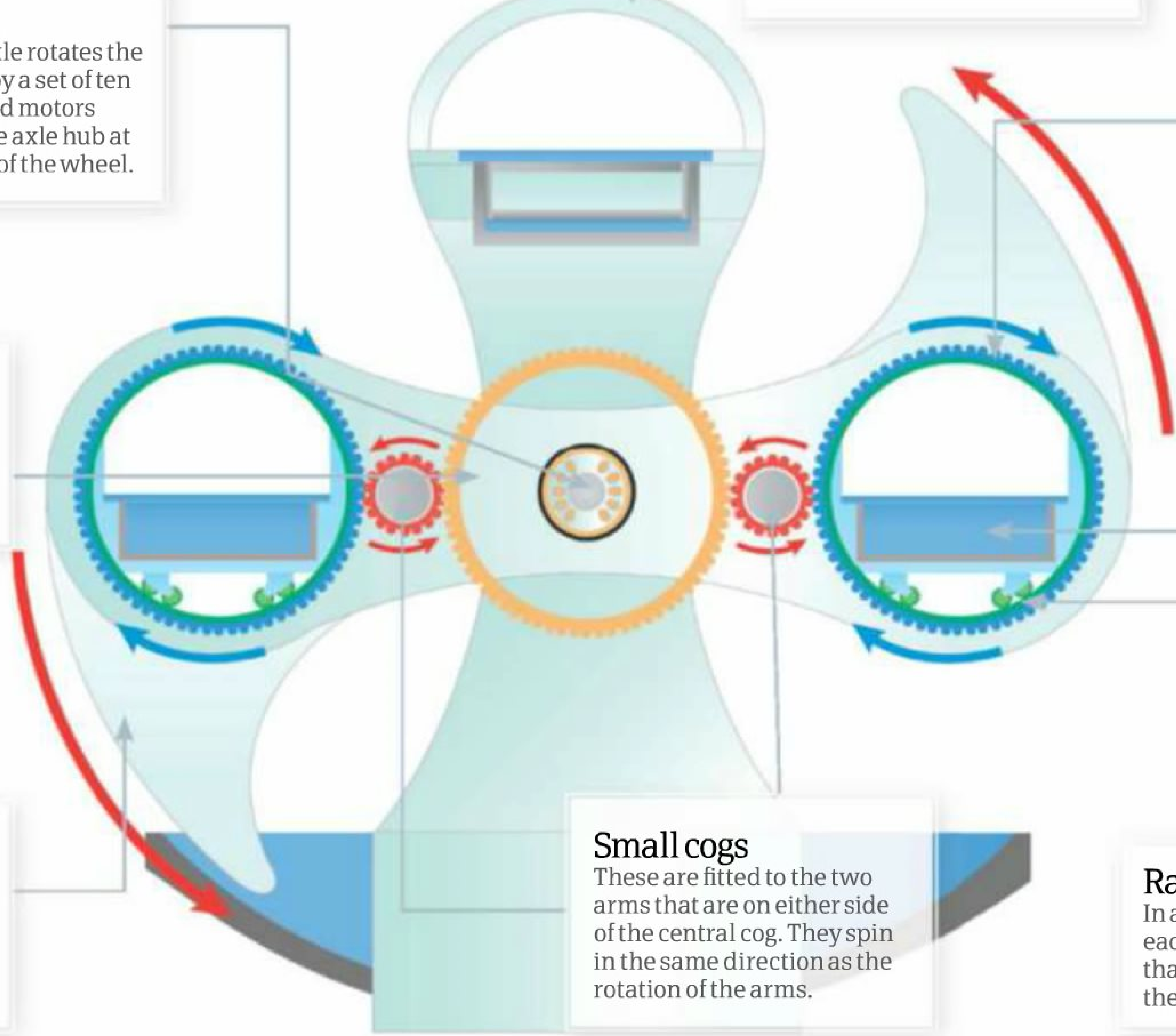
The height between the two canals of 25 metres (82 feet) took several hours to negotiate through the old lock system. With the wheel it takes about 15 minutes. Slopes and lifts were considered, but a wheel was the most innovative solution. Instead of turning a full circle, this wheel has two caissons (gondolas) that are equally balanced, which travel 180 degrees between the lower basin and the aqueduct. Each caisson on the wheel can take several boats simultaneously, side-by-side, or a single boat up to 21.3 metres (70 feet) in length and six metres (19 feet) wide. The heaviest vessel that each gondola can carry is 200,000 kilograms (440,925 pounds).

Since there is so much stress on the steel structure, it is bolted together rather than welded; in fact, 15,000 hand-tightened bolts were used in its assembly. It was opened by Queen Elizabeth II on 24 May 2002 and is intended to have a life span of 120 years.

© Thinkstock

The wheel in action

What mechanisms enable this to elevate boats almost half the height of Nelson's Column?



Aqueduct
Concrete piers support the aqueduct. The last pier of the aqueduct, located next to the wheel, contains the drive chamber for the wheel's motors.

Central axle
This 3.5m (11.5ft) axle rotates the arms. It is driven by a set of ten hydraulic-powered motors located around the axle hub at the aqueduct end of the wheel.

Outer cog
The small cogs cause the 8m (26ft)-diameter outer cogs, attached to both gondolas, to rotate at the same speed but in the opposite direction to the arms.

Central cog
This 8m (26ft)-diameter cog is fixed to the main upright on the aqueduct side of the arm, and remains stationary.

Gondola
The two 6.5m (21ft)-wide, diametrically opposed caissons can each carry 250,000l (55,000ga) of water.

Arm
Designed in the shape of the Celtic double-headed axe. The two arms are 25m (82ft) apart and extend 15m (50ft) from the central axle.

Small cogs
These are fitted to the two arms that are on either side of the central cog. They spin in the same direction as the rotation of the arms.

Rail
In addition to the system of cogs, each arm opening has a curved rail that engages with small wheels on the caissons to keep them level.

What is a superferry?

A new wave of technologically advanced ferries is transforming sea voyages, transporting passengers at extreme speeds with unprecedented levels of luxury

Ferries traditionally were seen as one of the most basic forms of marine transport, carrying limited numbers of people, vehicles and cargo over short distances. Those days, however, are currently being blown away with a new breed of superferry. These machines not only boast some of the world's most advanced marine engineering and tech, but also blur the line between a ferry and a full-blown cruise liner, offering customers a travel speed and facilities usually exclusive to planes, trains and automobiles.

This new class of superferry is probably best showcased with Stena Line's Hollandica and P&O Ferries' Spirit of France vessels, with each delivering a jaw-dropping level of technical wizardry. The Hollandica, which runs from Harwich, UK, to the Hook of Holland is one of the largest superferries on the planet, measuring in at a colossal 240 metres (787 feet) in length. Further, the vessel can not only comfortably carry 1,200 passengers per transit, but also host 230 cars and over 300 freight vehicles in its hold. That's all from a vessel that weighs 63,600 tons and that, even when fully loaded, can cruise at over 21 knots (40 kilometres/ 25 miles per hour). This speed is granted by two 7,200-kilowatt (9,655-horsepower) MAN 6L48/60CR and two 9,600-kilowatt (12,874-horsepower) MAN 8L48/60CR diesel engines.

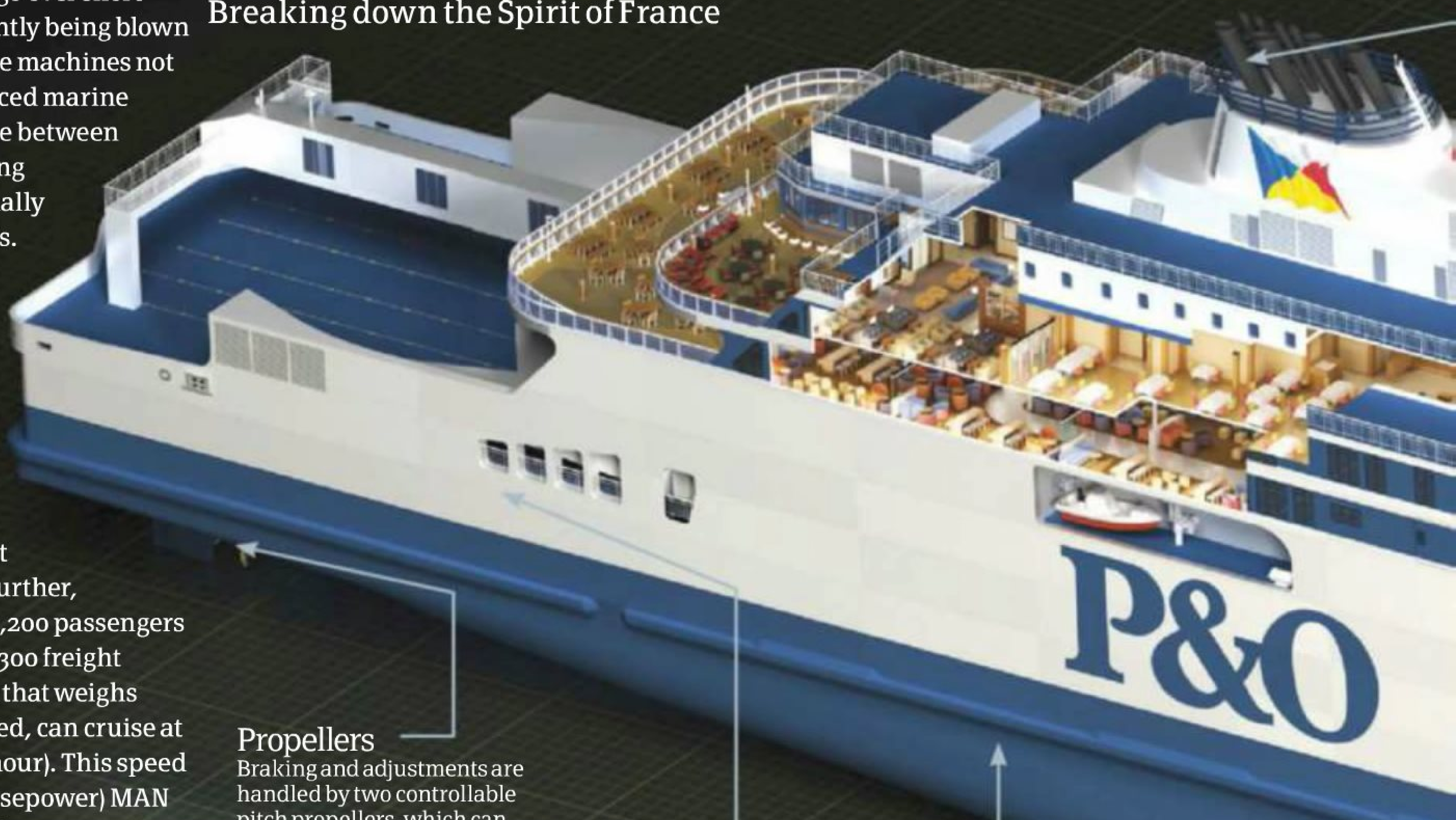
There are over 538 cabins fitted onto the ship, with a total of 1,376 beds. Each cabin comes with an en-suite bathroom and full-sized beds rather than bunks. In addition, the ferry comes equipped with multiple restaurants, a full-scale cinema, several bars, a lounge, media room and an internet café. Finally, each cabin and lounge has its own satellite TV installed.

Not to be outdone, however, is P&O's Spirit of France. Measuring in at 213 metres (699 feet) in length, weighing over 49,000 tons and delivering a top speed of 22 knots (41 kilometres/25.5 miles per hour) – thanks to four vast MAN 7L 48/60 diesel engines – this superferry can cross the English Channel from Dover to Calais in under two and a half hours. Not only that, but as a result of its advanced hydrodynamic hull it can conserve large quantities of fuel when compared to legacy models.

While the Spirit may lose out in size and weight to the Hollandica, it makes up for it in its ability to transport 2,000 passengers, as well as 160 articulated lorries or up to 1,059 cars on any one transit, securing vehicles in its multi-tiered hold. Passengers are spoilt for choice with its wide array of eateries, lounges, entertainment suites, bars and observation galleries, as can be seen in our stunning cutaway image. ✺

Anatomy of a superferry

Breaking down the Spirit of France



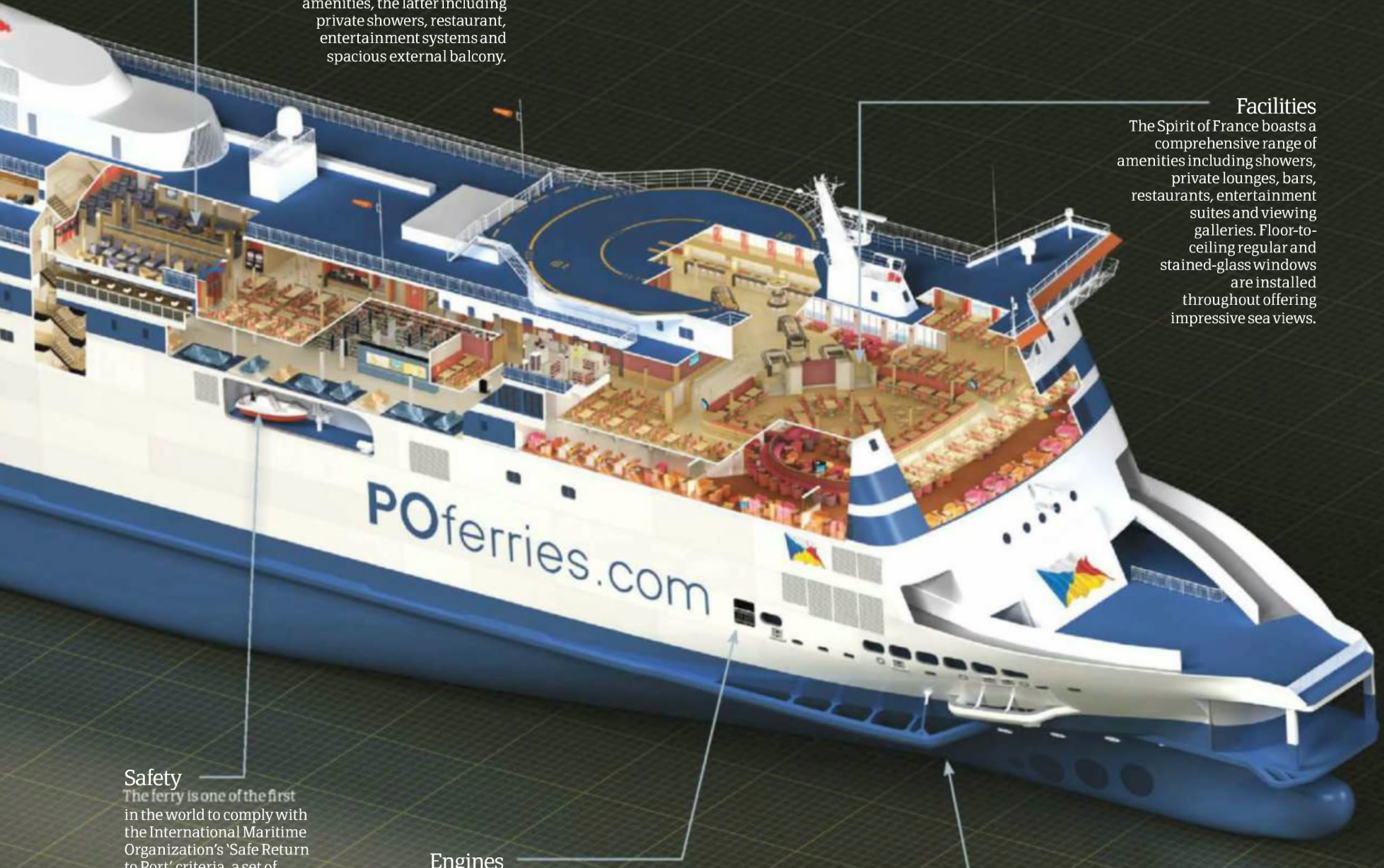
Propellers
Braking and adjustments are handled by two controllable pitch propellers, which can vary their pitch even into negative values. By doing so, they grant the Spirit vast reverse thrust when needed.

Hold
The Spirit's hold is colossal and is capable of securely carrying up to 160 lorries or 1,000-plus cars per transit. The hold is accessed via the rear of the vessel by a hydraulically operated gangway.

Hull
The Spirit's hull, which was designed by shipbuilding contractor STX Europe, has been designed to optimise hydrodynamic efficiency, with its shape and materials delivering superior fuel consumption during transits.

The Spirit of France is the largest-ever ferry to operate in the English Channel

> “The ferry comes equipped with multiple restaurants, a full-scale cinema, several bars, a lounge, media room and an internet café”



Exhaust
One of the most advanced pieces of technology on board the Spirit of France is a system that captures waste exhaust gases and then uses them to heat boilers that, in turn, generate steam to power the ship's water treatment plant.

Freight
The ferry is specifically tailored towards freight drivers, providing them with their own lounge and amenities, the latter including private showers, restaurant, entertainment systems and spacious external balcony.

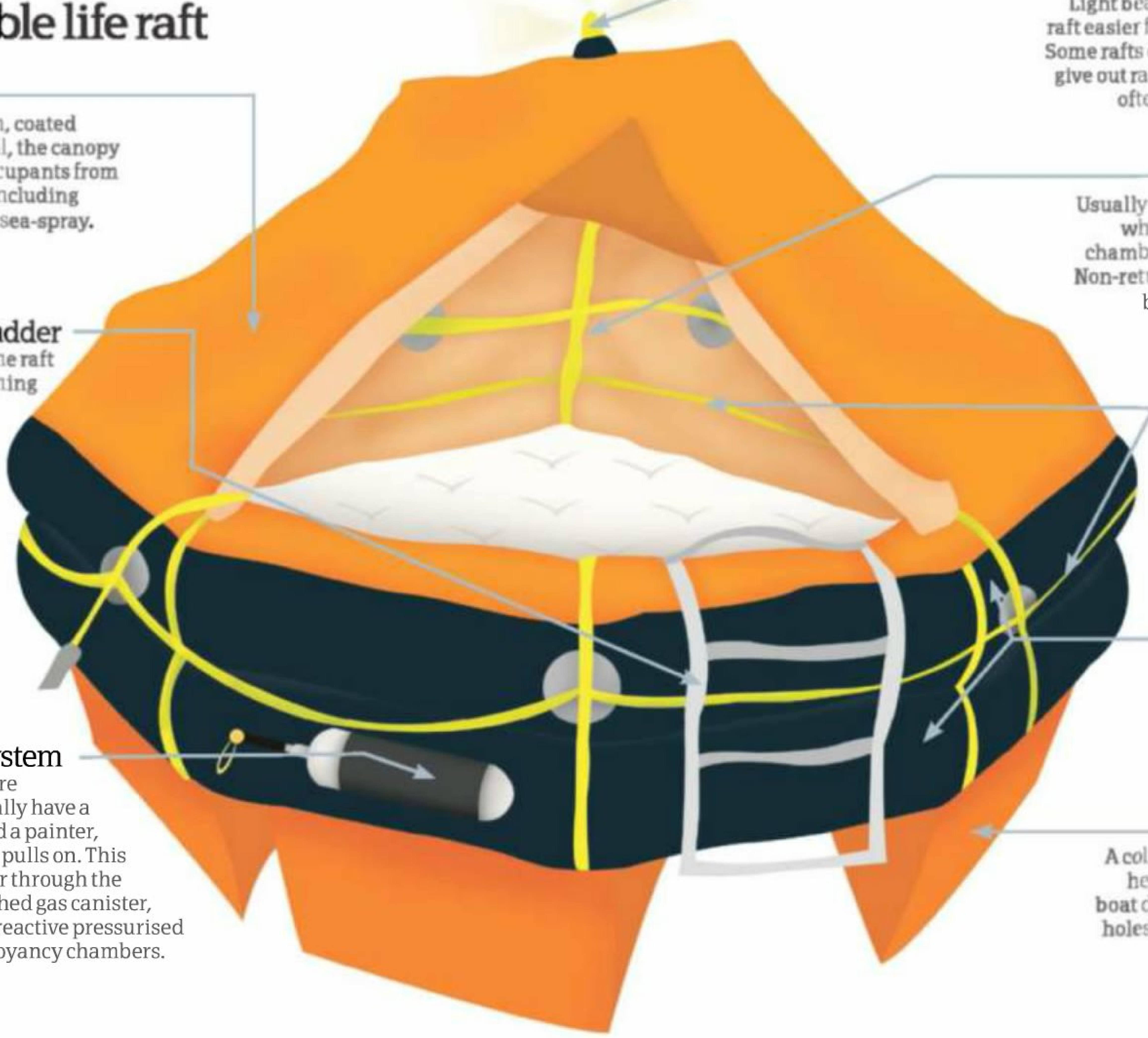
Facilities
The Spirit of France boasts a comprehensive range of amenities including showers, private lounges, bars, restaurants, entertainment suites and viewing galleries. Floor-to-ceiling regular and stained-glass windows are installed throughout offering impressive sea views.

Safety
The ferry is one of the first in the world to comply with the International Maritime Organization's 'Safe Return to Port' criteria, a set of rules that require the ferry to be able to continuously supply basic services in the event of an incident.

Engines
The Spirit of France is equipped with four huge MAN 7L 48/60 diesel engines, each delivering 7,600kW (10,190hp). Combined, these engines serve up a colossal 30,400kW (40,767hp) of power.

Thrusters
Three colossal bow thrusters are installed in the forward part of the Spirit's hull. These are transversal propulsion devices that allow the captain to turn the vessel to port or starboard without touching the main propulsion. They are essential for smooth docking.

The main features of an inflatable life raft



Canopy
Made of a tough, coated rubber material, the canopy protects the occupants from the elements, including wind, rain and sea-spray.

Boarding ladder
On the side of the raft there is an opening for stricken passengers to enter via a small rope ladder that's made from nylon straps.

Inflation system
Life rafts that are inflated manually have a long cord called a painter, which the user pulls on. This forces a plunger through the seal of an attached gas canister, releasing non-reactive pressurised gas into the buoyancy chambers.

Exterior strobe light
Light beacons on top of the canopy make the life raft easier for rescue vessels/planes to see at night. Some rafts come equipped with transponders that give out radio waves and the emergency pack will often include high-intensity lights to make survivors more visible too.

Arch tubes
Usually also inflatable, these structural arches, which are inflated via the upper buoyancy chamber, support the raft's protective canopy. Non-return valves ensure that even if the upper buoyancy chamber bursts this essential framework will not collapse.

Exterior and interior life lines
These durable life lines are to be gripped during bad weather. Other items attached to the outside of the craft include a sea anchor (or drogue), a rescue quoit and a buoyant knife.

Buoyancy chambers
The raft typically has two separate inflatable floors, so in case of a puncture there is still some buoyancy to keep afloat. These chambers can be pumped up and deflated manually too.

Ballast compartments
A collection of ballast bags beneath the craft help to prevent capsizing by weighing the boat down sufficiently. These bags have large holes in the top to help them fill quickly with a suitable volume of seawater.

How do inflatable life rafts work?

The humble inflatable dinghy is still saving lives all over the world today

Inflatable life rafts are stored visibly on board a vessel in either canvas holdalls, fibreglass containers, or all-weather synthetic plastic carry cases. The rafts themselves are made of corrosion- and abrasion-resistant, polyurethane-coated nylon, a super-tough but light material.

The standard inflatable life raft can be launched by throwing it overboard and climbing in or by lowering it into the water using a mechanical winch on the side of the vessel, called a davit. If passengers tug on the 'painter' – the cord that releases compressed gas from a canister into the raft – the dinghy will inflate in a matter of seconds.

However, they can also be deployed by hydrostatic release units (or HRUs), which connect the sealed life raft container to the vessel's deck. When the boat starts to sink, water pressure triggers the HRU to sever the main tie binding the raft to the deck. As it sinks, more tension is placed on the painter until it eventually gives way, releasing gas into the buoyancy chambers.

25
Persons
91

© Alamy

How do kayaks shoot rapids?

A look inside these versatile boats

Kayaks are small, narrow boats – most commonly single-seater – designed to transport their user over a variety of watery environments, be that calm, flat lakes, choppy coastal waters or torrential river rapids. Due to their ability to traverse such varied terrains, kayaks can take many forms. For example, racing kayaks are long and narrow – often exceeding six metres (19 feet) in length – to reduce drag and maximise the distance per stroke generated by the paddler's oar. On the other hand, white-water kayaks are short and squat, often measuring in at no more than 1.5 metres (five feet) as stability and the ability to turn sharply are the key requirements when navigating jagged rocks and steep drops.

Indeed, when you consider this diverse usage, it won't come as a surprise to discover that there are over six main categories of kayak, including: recreational, oceanic, white-water, racing, surf and hybrid types.

Rudder
Due to their great length, sprint kayaks can be fitted with a small rudder to aid turning, which is controlled by the paddler's feet.

Chassis
Modern kayak chassis are constructed from carbon fibre, fibreglass or wood. This ensures a light weight and therefore higher speed.

Beam
The beam, or widest part, of a kayak, is rarely much wider than the kayaker's width. This greatly reduces the drag experienced by the kayak.

What are life jackets made of?

Designed to be fast and responsive if and when it is needed, how does this essential aid to surviving in water inflate so quickly?

Inflatable life jackets consist of one or more internal bladders that are inflated in an emergency. They can be manually operated or automatically triggered. Manual systems require the user to pull a lanyard that causes a mechanism to puncture a canister of carbon dioxide (CO2) gas, which then expels to rapidly inflate the bladder. The whole process takes just three seconds to fully inflate the life jacket.

Automatic life jackets also have CO2 gas canisters inside them to inflate the bladder. They come in two forms. The first has a firing pin that is held in place by a small pellet. When the pellet hits the water it quickly dissolves and triggers the firing pin, causing the gas from the canister to be released and therefore inflating the jacket. The second type is the hammer or hydrostatic jacket, which has a pellet enclosed in casing linked to a hydrostatic valve. The valve will only open to dissolve the pellet, and then fire the gas canister, when it is a few centimetres below the surface of the water.

Automatic life jackets usually have a manual trigger mechanism as a backup, and all life jackets have a tube to enable the user to blow the jacket up if all else fails.

> "Automatic life jackets usually have a manual trigger mechanism as a backup"

How do snowmobiles work?

Read on to find out how these vehicles traverse icy terrain

In the pursuit of getting from A to B as quickly as possible, it was only a matter of time before traditional skis were replaced when traversing snow and ice, and the snowmobile invented. The roots for this snowy-terrain vehicle are in military technology, where the rubber in the off-road tracks was proven to work even in adverse winter conditions.

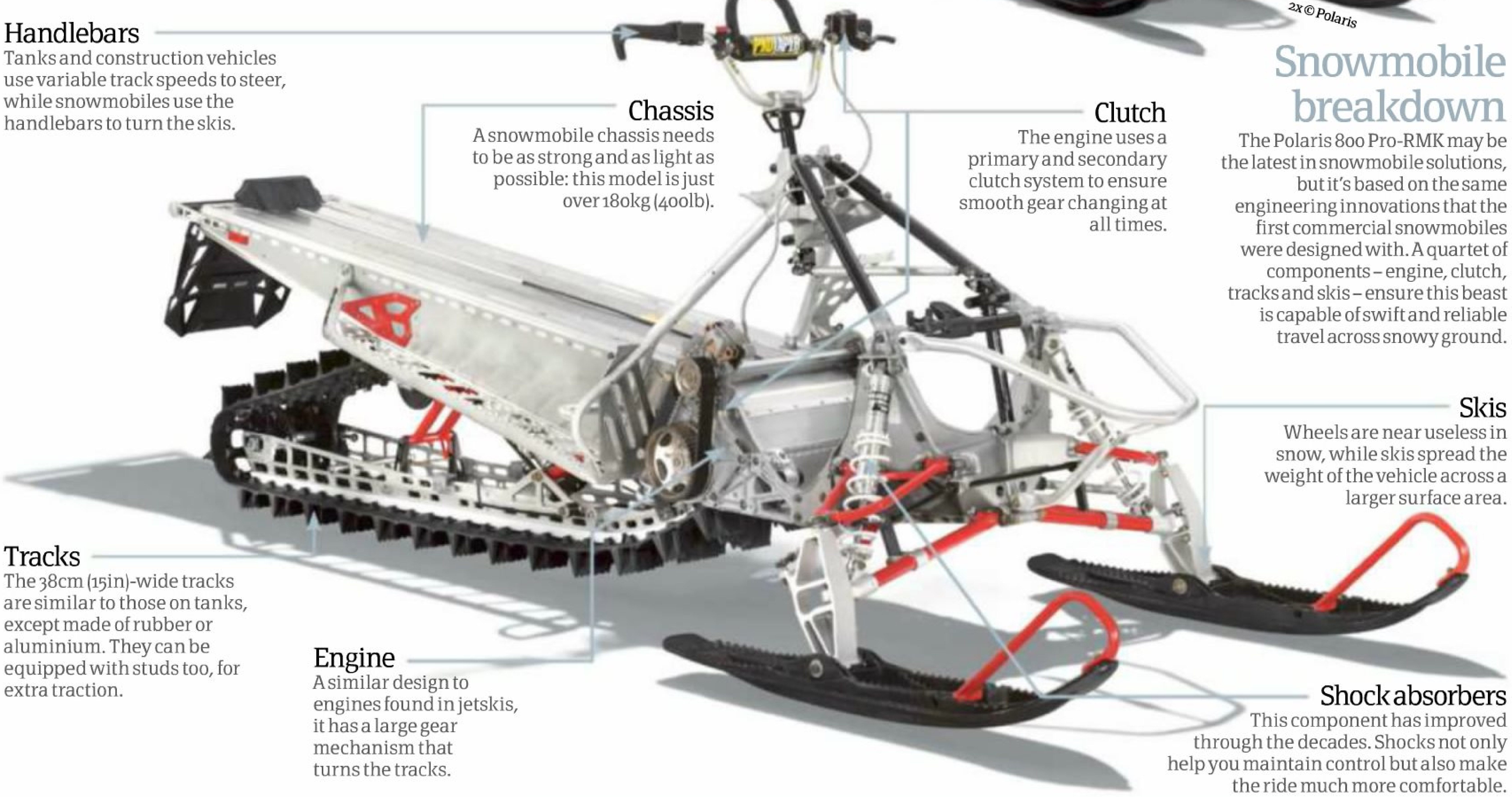
A Canadian inventor called Joseph Armand Bombardier took the design, adapted and refined it to create the first single-passenger snowmobile in 1959: the Ski-Doo. Bombardier Industries has gone on to be a leader in the snowmobile market, while the snowmobile itself has become the de facto standard for fast travel across ice and snow-dominated landscapes.

Windshield
Keeping the wind out of your face is even more important in freezing arctic conditions.

2x © Polaris

Snowmobile breakdown

The Polaris 800 Pro-RMK may be the latest in snowmobile solutions, but it's based on the same engineering innovations that the first commercial snowmobiles were designed with. A quartet of components – engine, clutch, tracks and skis – ensure this beast is capable of swift and reliable travel across snowy ground.



Handlebars
Tanks and construction vehicles use variable track speeds to steer, while snowmobiles use the handlebars to turn the skis.

Chassis
A snowmobile chassis needs to be as strong and as light as possible: this model is just over 180kg (400lb).

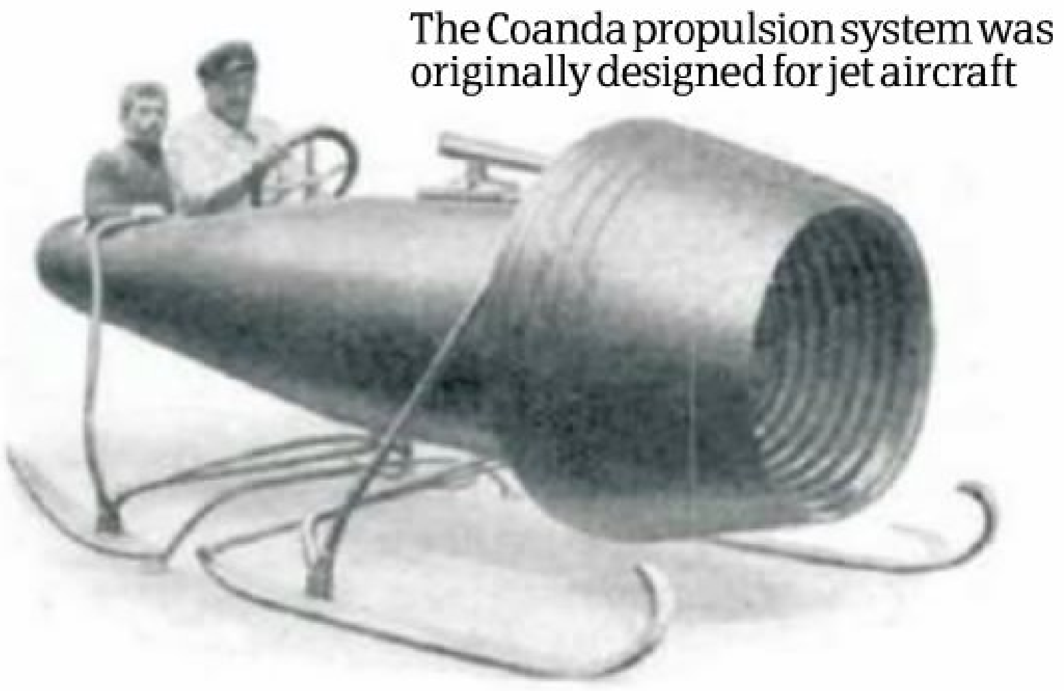
Clutch
The engine uses a primary and secondary clutch system to ensure smooth gear changing at all times.

Skis
Wheels are near useless in snow, while skis spread the weight of the vehicle across a larger surface area.

Tracks
The 38cm (15in)-wide tracks are similar to those on tanks, except made of rubber or aluminium. They can be equipped with studs too, for extra traction.

Engine
A similar design to engines found in jetskis, it has a large gear mechanism that turns the tracks.

Shock absorbers
This component has improved through the decades. Shocks not only help you maintain control but also make the ride much more comfortable.



The Coanda propulsion system was originally designed for jet aircraft

Aerosans proved to be versatile vehicles in snowy terrain

The aerosan

Military use of the snowmobile dates back to the early-20th Century, when the Soviet Red Army used a light vehicle on skis that used an aeroplane propeller, called the aerosan. It was used as a transport and light-goods vehicle for medical supplies at first, but during the 1939-1940 Winter War against Finland, the KM-5 and OSGA-6 were equipped with a machine-gun and proved useful reconnaissance and raiding vehicles.

What makes the jet-propelled wing fly?

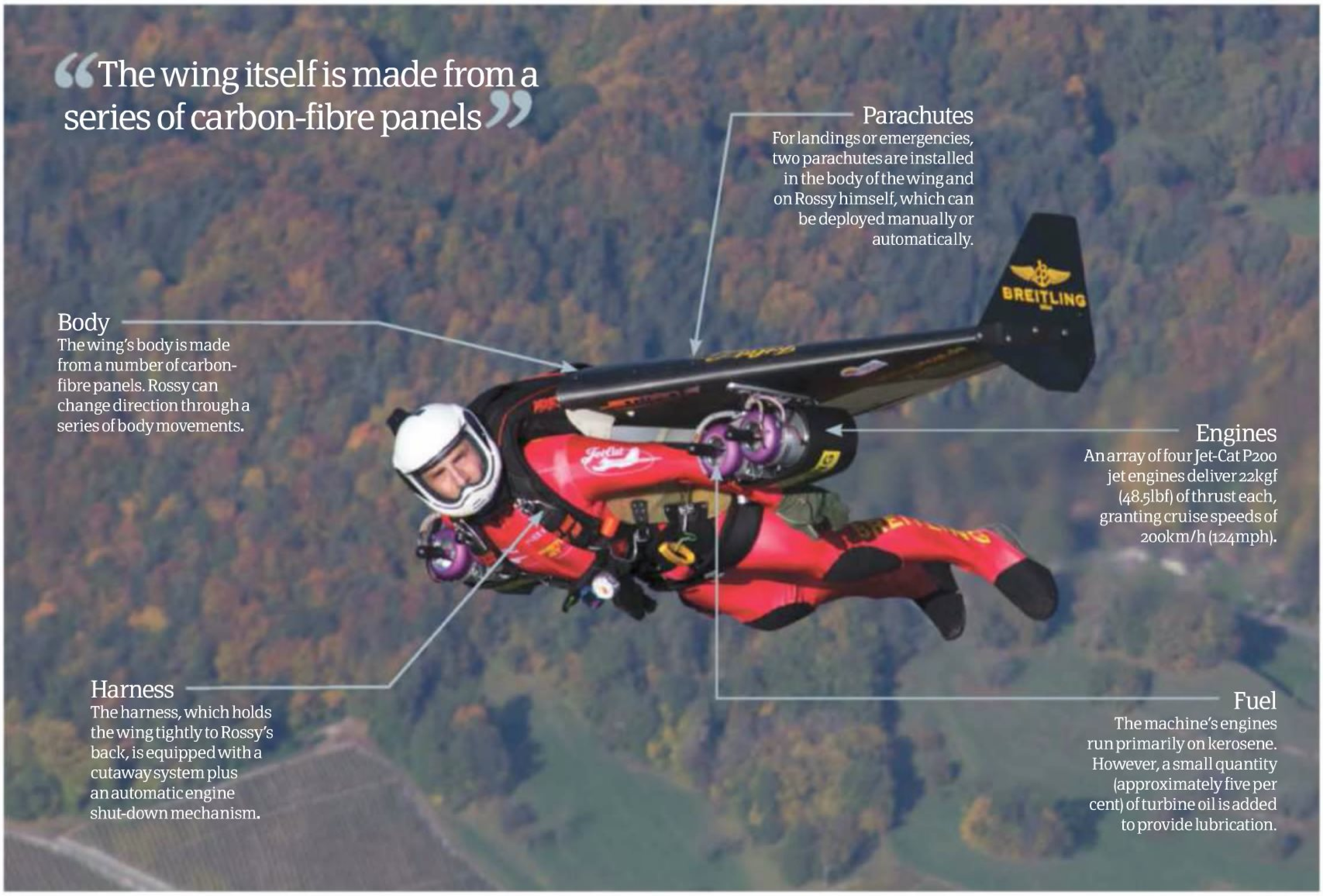
We break down Yves Rossy's jet-powered personal flying machine that enables him to soar at nearly 200mph through the sky

Jetman, aka pilot Yves Rossy, is the world record holder for jet-propelled wing flight, successfully performing a series of jaw-dropping flights at speeds of up to 304 kilometres (189 miles) per hour.

He achieves these feats with his jet-propelled wing, a personal jetpack-style flying machine that is attached to Rossy much like a backpack, via a multi-point harness. The wing is powered by four small-scale jet engines, which are scaled-down replicas of those found on fighter aircraft. The engines burn a kerosene/turbine oil mix and each generates a modest 22 kilograms-force (48.5 pounds-force) of thrust – enough to enable Jetman to sustain low-altitude flight for 10-20 minutes depending on his speed and atmospheric conditions.

The wing itself is made from a series of carbon-fibre panels, which are bolted together to form a two-metre (6.6-foot)-wide main body. Attached to this are the wing's four jet engines as well as the fuel tanks, which sit either side of Rossy who is positioned at the top-centre of the aircraft. Due to the large power and heat generated by the wing's engines, Rossy himself must wear a specially designed wing-suit when piloting it. This suit is designed to be heavily heat resistant and works in partnership with a carbon-fibre heat shield installed around the vehicle's exhaust tail.

The jetwing is controlled by a combination of Jetman's own head, arm and leg movements, and an engine throttle. Together, these enable Rossy to climb, descend and sweep left and right gracefully, without spinning out of control. However, in the event that a mechanical failure or other emergency were to occur, the wing can be detached and both Rossy and the device can land safely using parachutes.



"The wing itself is made from a series of carbon-fibre panels"

Parachutes
For landings or emergencies, two parachutes are installed in the body of the wing and on Rossy himself, which can be deployed manually or automatically.

Body
The wing's body is made from a number of carbon-fibre panels. Rossy can change direction through a series of body movements.

Engines
An array of four Jet-Cat P200 jet engines deliver 22kgf (48.5lbf) of thrust each, granting cruise speeds of 200km/h (124mph).

Harness
The harness, which holds the wing tightly to Rossy's back, is equipped with a cutaway system plus an automatic engine shut-down mechanism.

Fuel
The machine's engines run primarily on kerosene. However, a small quantity (approximately five per cent) of turbine oil is added to provide lubrication.

How does an aircraft carry weaponry?

Hardpoints enable fighter aircraft to carry a plethora of deadly weapons, gallons of extra fuel and electronic countermeasures

Hardpoints, also commonly referred to as weapon stations, are any part of an aircraft's airframe that has been designed to carry an external load. These loads commonly involve additional weaponry, fuel or other forms of countermeasures, the latter usually consisting of braces of flares.

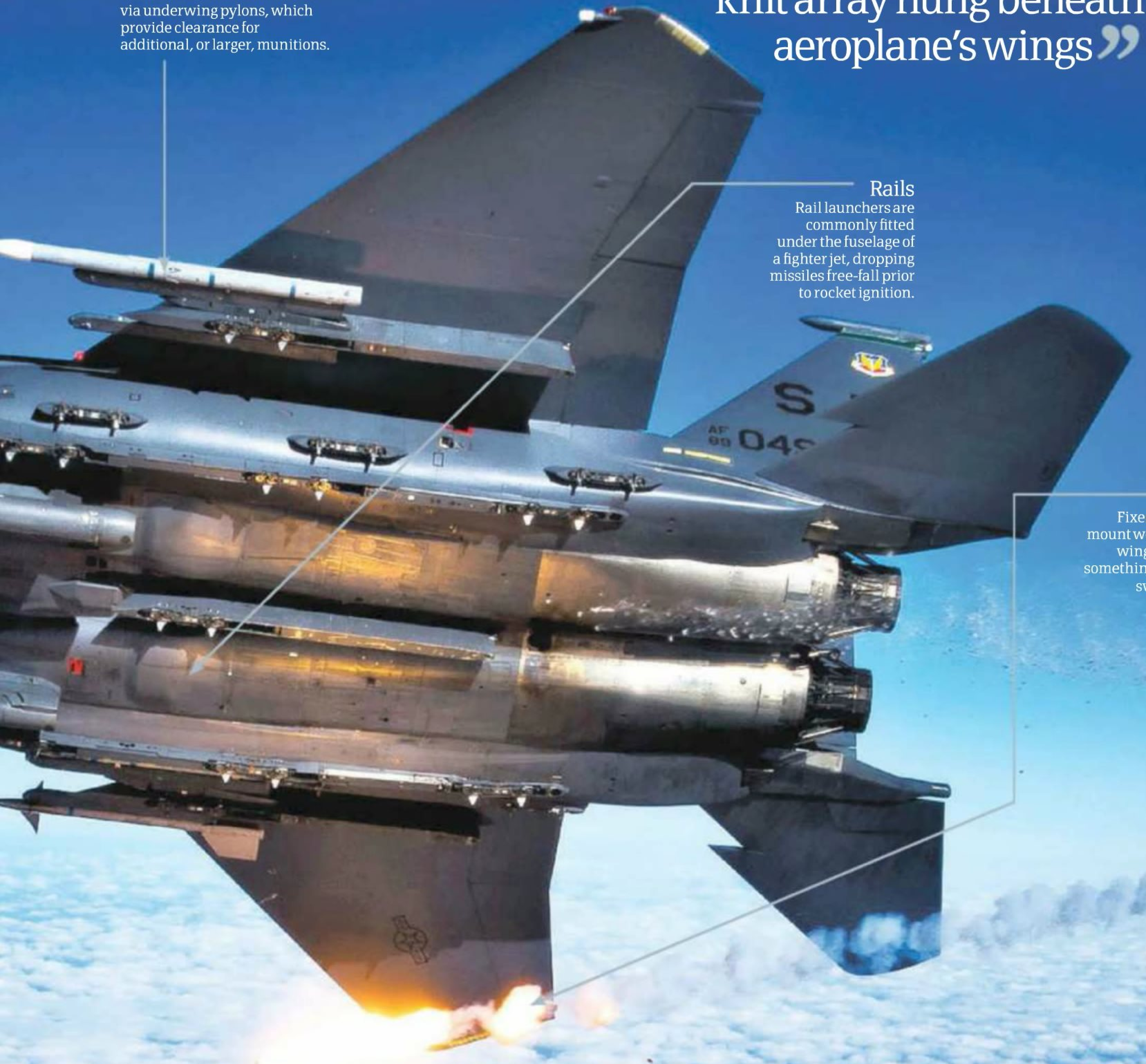
There are three main types of hardpoint, each with its own unique advantages and disadvantages. The first type is rail launchers, which are used to carry and launch large missiles and rockets. These comprise thin narrow rails mounted under an aircraft's fuselage, to which missiles are attached by a basic slot mount. These rail systems work by simply dropping the missile on command from the mount, with the weapon then propelling itself clear of the plane under the power of its own ignited engine and kinetic energy. Certain fighter aircraft sport modified variants of this rail hardpoint, often recessing it into the fuselage in order to reduce drag. In these cases, an ejector system is built in to the rail, which physically 'kicks' the missile out and away from the rail to ensure clearance.

Ejector racks make up the second type of hardpoint, although technically speaking the rack is not a hardpoint but is attached to one via a pylon. Ejector racks consist of braces of free-fall bombs and small rockets in a close-knit array hung beneath an aeroplane's wings. The positioning of the rack away from the wing surface ensures that control surfaces are not disrupted (damaging the handling and agility of the aircraft). The ejector racks also work by physically pushing the bomb/missile free, this time using explosive cartridges, which when engaged destroy the rack's weapon hooks. To make sure the primed weapon is definitely released, each rack is equipped with both primary and secondary charges, as a backup.

The third common weapon station is the wet hardpoint. These are referred to as 'wet' as they are plumbed and capable of interfacing with drop tanks mounted on them. This allows an aircraft to carry extra stores of fuel outside of its primary reservoir, greatly supplementing its maximum combat range. Importantly, despite their connection to the aircraft's fuel tank, wet hardpoints can still be jettisoned when empty to reduce weight and drag, and also be used to mount additional weaponry if needed.

Lastly, any aircraft's hardpoints are numbered from left to right. So, for example, if an aeroplane's left wingtip mount is number one, its right wingtip mount would be, say, number six, with all other mounts sitting in between numbered accordingly.

> “Ejector racks consist of braces of free-fall bombs and small rockets in a close-knit array hung beneath an aeroplane’s wings”



Pylons
Ejector racks or single missiles can be mounted to an aircraft via underwing pylons, which provide clearance for additional, or larger, munitions.

Rails
Rail launchers are commonly fitted under the fuselage of a fighter jet, dropping missiles free-fall prior to rocket ignition.

Swing
Fixed-wing aircraft can mount weapons under their wings and on their tips, something not possible with swing-wing aircraft.

What is a hybrid bus?

Hybrid buses are an eco-friendly form of public transport. They are quieter, cleaner and more fuel-efficient than standard diesel buses. They reduce emissions of local pollutants and carbon dioxide by at least 30% compared to normal buses. They combine a standard engine and an electric motor so that they consume less fuel. The hybrid buses in London also have regenerative braking, which means they produce electrical energy whenever the brakes are engaged. This energy is stored in a battery pack and used to power the motor.

Why are London buses red?

The iconic red London bus has a long history. In 1907, at a time when there was fierce competition for passengers and routes were just introduced, operators still used a variety of colours to indicate where the bus was going. The largest operator, London General Omnibus Company, decided to make its buses stand out. It chose a spoked wheel as a symbol and the colour red for all its vehicles. When London Transport was eventually formed as a single company in 1933, red was already the predominant colour, so all buses in the Greater London area became red.

How does skywriting work?

Skywriting is achieved by partnering a lightweight aircraft, typically with a short turning circle, with a special system of pressurised containers and injection pumps. The smoke used to 'paint' a word or symbol onto the sky is generated by the vaporisation of low-viscosity oil in the aeroplane's engine manifold. This oil is held in a pressurised container and pumped when needed – either manually or via a preprogrammed GPS unit – into the manifold to generate smoke for the writing or drawing.

Typically each constructed letter is roughly 1.6 kilometres (one mile) in length and approximately 3.2 kilometres (two miles) above the Earth's surface. An average five-letter word would be painted across 16 kilometres (ten miles) of sky and require more than 15 precisely performed manoeuvres by the pilot.

How do catamarans stay afloat on water?

Catamarans have a number of design elements that put them among the fastest sail/motorised vehicles on the seas. The hulls of a sail-powered catamaran are made of fibreglass fabric, foam or another lightweight material, allowing them to catch a large amount of wind. This allows the catamaran to reach a higher speed, as there is less contact with the water.

When compared to a single-hulled boat, the twin-hull shape of a catamaran has more advantages. The wide berth of the two hulls makes the whole boat very stable. This means that the sail is more likely to stay upright in a heavy gust than that of a monohull, allowing it to draw more power and be larger than that on a single-hull. This stability also means that a catamaran does not need a counterweight to prevent it tipping over, making it very light and easily manoeuvrable, although there is an increased risk of capsizing. The hulls of a catamaran are much thinner than those on a single-hulled boat, meaning that there is a smaller surface area in contact with the water and therefore less friction, which allows them to reach higher speeds.

What were horse trams and buses?

Horse buses were pulled by two horses and carried up to 26 passengers. Horse trams were bigger and had metal wheels, which ran on smooth tracks in the road making them much easier to pull. Two horses could pull a tram carrying 50 passengers. This was twice as many as buses could carry. Being able to carry more passengers than a bus with the same number of horses made trams cheaper to run, helping to bring public transport within the reach of ordinary working-class people for the first time in history.

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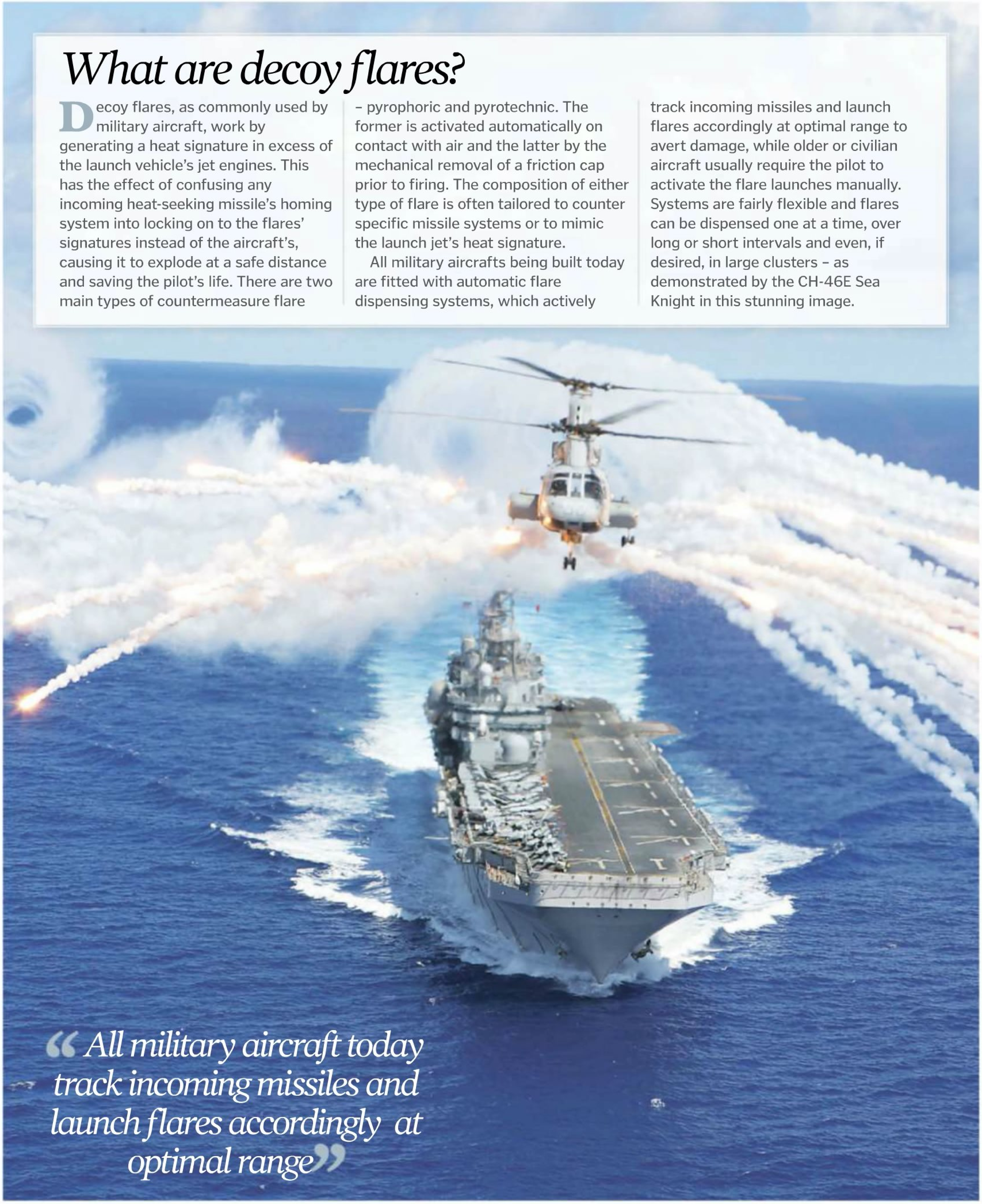
When did taxis first run on the meter system?

Taxi meters were made compulsory in motor cabs in July 1907 although a simple device to measure distance was used experimentally as early as 1847. Before meters became obligatory, resistance to any kind of regulation was fierce and overcharging was common. Once they became compulsory, in motor cabs though, many horse-cab owners adopted them in order to compete for customers, even though they weren't required to have them. There were only 723 motor cabs on the streets of London in 1907 – hugely outnumbered by 9,789 horse cabs. However, by 1910, the position had reversed with a total of 6,397 motor cabs on the road compared to only, 724 horse cabs, which less to their mass acceptance and usage.

What are decoy flares?

Decoy flares, as commonly used by military aircraft, work by generating a heat signature in excess of the launch vehicle's jet engines. This has the effect of confusing any incoming heat-seeking missile's homing system into locking on to the flares' signatures instead of the aircraft's, causing it to explode at a safe distance and saving the pilot's life. There are two main types of countermeasure flare – pyrophoric and pyrotechnic. The former is activated automatically on contact with air and the latter by the mechanical removal of a friction cap prior to firing. The composition of either type of flare is often tailored to counter specific missile systems or to mimic the launch jet's heat signature.

All military aircrafts being built today are fitted with automatic flare dispensing systems, which actively track incoming missiles and launch flares accordingly at optimal range to avert damage, while older or civilian aircraft usually require the pilot to activate the flare launches manually. Systems are fairly flexible and flares can be dispensed one at a time, over long or short intervals and even, if desired, in large clusters – as demonstrated by the CH-46E Sea Knight in this stunning image.



> "All military aircraft today track incoming missiles and launch flares accordingly at optimal range"

What is the dead man's handle?

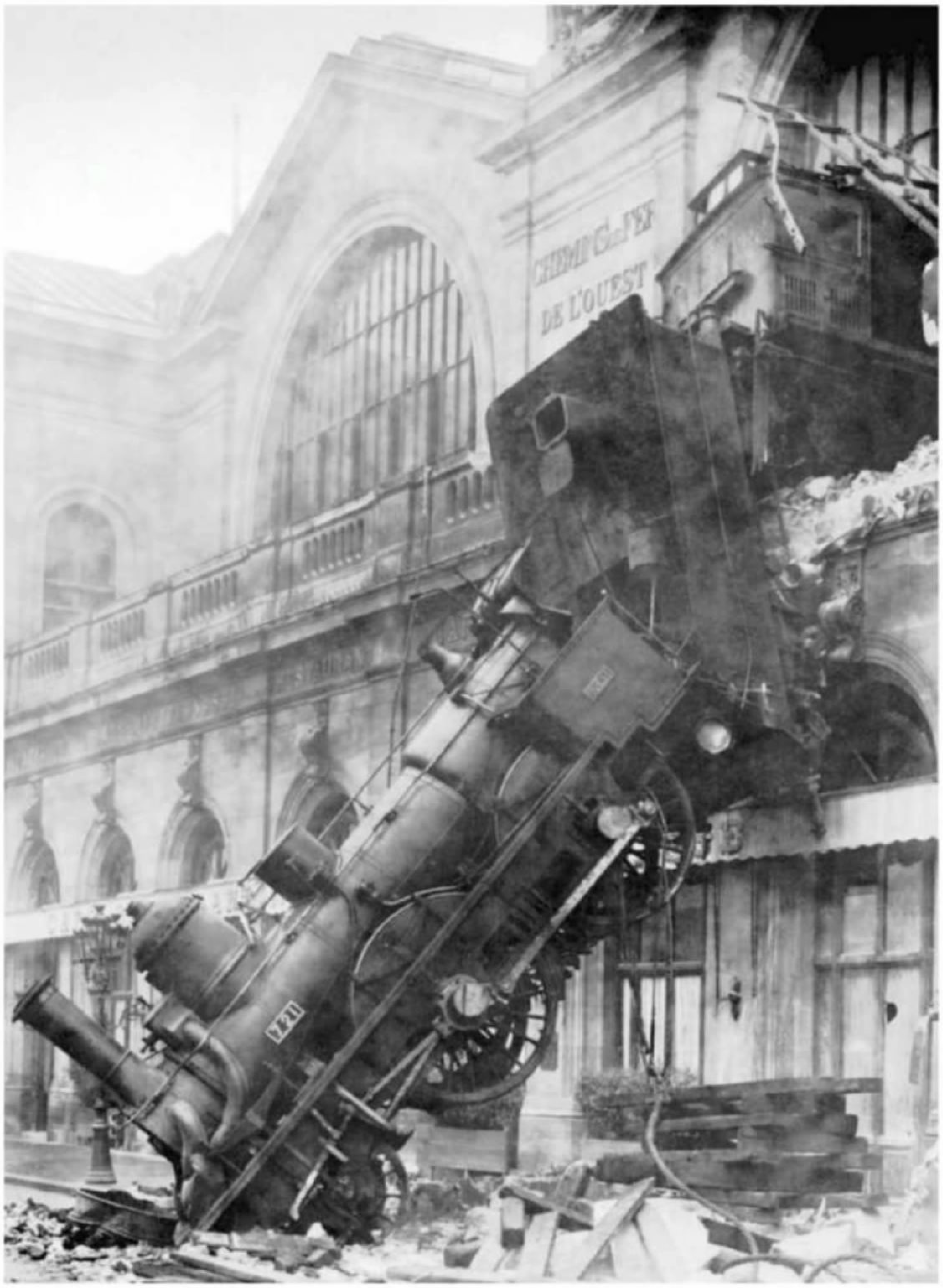
The 'dead man's handle' was designed to act in the event of a driver falling ill while on duty. With the introduction of electricity on the railways, at the end of the 19th Century, the fireman was no longer needed, so the driver worked alone in the cab. The alerting device consisted of a flat knob on top of the controller handle. This was supported by a spring weak enough to be held down without effort by the driver's hand when operating the controller handle. As long as the driver kept the knob down, the controller operated normally. If pressure was released for any reason (ie if the driver became unwell and lifted his hand for whatever reason) the current was immediately cut off and the brakes were applied to the engine. The device is still used today, albeit under a different name. Today, it is more commonly called a vigilance device.

* * *

Can you do a loop-the-loop in a passenger jet?

To perform a 360-degree loop, an aircraft needs to achieve three phases in quick succession: the entry, the climb and the exit. Each of these would cause problems for anything the size and weight of even a small jet. Entry has to be undertaken at top speed to carry the plane through vertical ascent, making optimum fuel load a tricky calculation.

At this velocity, the climb would put massive strain on the wings and tail – enough to tear them from the fuselage. Finally, the jet's weight would be too great and flight controls too weak to pull out of the loop without causing vibrations that could rip the aircraft apart. Needless to say, nobody has found a pilot brave enough to try this manoeuvre.



What caused the train wreck at Montparnasse in 1895?

This incredible photo of the wreck at Gare Montparnasse in Paris shows a very dramatic scene of a train that has crashed through the wall and partially tumbled to the street. The cause? Both mechanical failure and human error. The train was late, so the driver had it pull into the station at a high speed. It had two different types of braking systems: handbrakes and an air brake known as a Westinghouse brake. The conductor realised that the train was going too fast and applied the Westinghouse brake. However, this didn't work. He then waited too long to use the handbrakes, which weren't sufficient enough given the weight of the train and speed at which it was travelling. The locomotive crashed through a wall and the first few cars fell towards the street below. Amazingly, only a few passengers and train employees were injured, though one pedestrian on the road below was killed.

What are funicular railways?

Funicular railways – also commonly known as incline railways – are typified as two connected rail carriages running over a steeply inclined four, three or two-rail track. Both carriages are connected as they operate under the principle of counterweight. In order to overcome the lack of traction generated by steel rails and tram wheels, but also maintain the minimal rolling resistance they deliver, funicular railways use each of their pair of carriages to power and balance the other over a central, top-mounted pulley.

With this design, very little electrical power is required to haul many tons of carriage up a steep incline, with the only additional power needed to initialise the pulley's motor. The pulley provides enough force to overcome the difference in weight between the two carriages (ie passengers) as well as counteract any friction between the two forces.

How does a gyroplane work?

While a gyroplane may look like a small helicopter, it has a lot more in common with a light aircraft. Unlike a traditional chopper, the freely rotating blades atop a gyroplane generate lift without the help of a powered engine. Instead, the blades are self-powered by the air that flows over them – this is called auto-rotation. The spinning blades enable the vehicle to ascend, descend or remain level during flight.

Gyroplanes do indeed have an engine to power a forward or rear-facing propeller, but the thrust provided is used to propel the gyroplane forwards, rather than power the rotor blades. The forward movement creates an upward airflow through the rotor blades from underneath; this in turn causes the blades to turn, generating lift.

Although these vehicles might appear rather insecure, gyroplanes are very safe. If the engine were to fail, the force of the wind through the blades would keep them spinning at the same speed regardless.

Which is the busiest Tube station on the London Underground?

During the three-hour morning peak hour, London's busiest Tube station is Waterloo, with 57,000 people entering. The busiest station in terms of passengers each year is also Waterloo with 82 million. The original Tube station was opened in 1898 by the Waterloo & City Railway, which was not – at that time – part of the Underground. The Baker Street & Waterloo Railway operated its services there from 1906. It soon adopted its popular nickname, the 'Bakerloo' line, which persists to this day.

©LennartCoopmans

When was the first Formula 1 car built and how fast was it?

Many cars were built to compete in the Formula One World Championship, but the first one to win it was the Alfa Romeo 158 in 1950. It was driven by Italian Giuseppe Farina during 1950, in which he won three races out of seven. One of the most successful racing cars ever produced, the 158 and its derivative, the 159, took 47 wins from 54 Grands Prix it entered. In the hands of drivers such as Giuseppe Farina, Juan-Manuel Fangio and Luigi Fagioli, it dominated the first two seasons of the Formula One World Championship. It was capable of driving at 290km/h (180mph).

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202 .... What goes on in the Hypervelocity Gun Lab?
204 .... Bitesize Q&A

“Early in its formation, the Earth spun up to five times faster than it does now”

Space

How was the solar system created?

The fascinating story of how our Sun and all its orbiting celestial bodies were created

Until 500 years ago, the Earth was at the centre of the universe and had been since the dawn of time. Orbiting the Earth was the Sun, Moon, stars and planets of Mars, Mercury, Venus, Jupiter and Saturn. Then, in the 16th-17th centuries, the three astronomers Copernicus, Kepler and Galileo turned two millennia of scientific belief on its head with the theory of heliocentrism – the idea that the Earth and planets revolve around the Sun: in other words, the Solar System.

The notion was vehemently opposed by the Church until the 18th Century, when a growing number of prominent members of society began to question conventional wisdom. It allowed French scientist Pièrre-Simon Laplace to formulate one of the first origin of the Solar System theories that had a hard scientific basis. His Nebular Hypothesis first appeared in his 1796 book Exposition Of A World System, which suggested that the Solar System was originally a spinning cloud of gas that condensed to form the Sun and the planets – not exactly light years from the way most astronomers believe the Solar System came to be today.

20th-Century physics and mathematics allowed for more cohesive theories as to the origins of the planets, but one idea they all had in common was that their creation started with a nebula. In the wake of Edwin Hubble's discovery that the Milky Way was just one of many galaxies in the cosmos, the Accretion Theory was proposed. Soviet astronomer Otto Schmidt suggested that the Sun in its present form had moved through a cloud of stellar particles and emerged on the other side surrounded by an envelope of gaseous dust. The Accretion Theory was modified by Raymond Lyttleton in 1961, but it still couldn't explain how the planets were formed from this material to everyone's satisfaction. Other explanations were put forward, including McCrea's Protoplanet Theory, in which a nebula collapsed and dust particles gathered to form protoplanets, and Capture Theory, where material from a protostar was captured by the Sun and eventually collapsed to create planets.

Although no origin of the Solar System theory is a certainty, it's Laplace's model that prevails today, albeit in a modified form. Modern Laplacian Theory kicks off with an ancient supernova, 5 billion years ago, which threw out a spectrum of elements and gas that collided with a hydrogen and helium nebula, seeding our embryonic Solar System. We can see this happening in other parts of our galaxy and beyond.

This cloud of material that included nitrogen, oxygen, iron and silica (all components vital for building an Earth-like planet) rotated slowly at first, but – under the force of its own gravity – gathered towards a central point, spinning faster and faster according to centripetal acceleration (the same force that causes a pirouetting ballerina to spin more rapidly when pulling their arms into the body). A denser cloud meant motes of dust could more easily coalesce to form small clumps that, in turn, grouped together over millions of years to form an enormous body at the centre – a protostar. The protostar was cold enough to collapse under its increasing mass and, as it did, a nuclear chain reaction was triggered that ignited it into a star similar to the Sun we know today.

But what of the planets we know of? How did they form and why does each one differ so much? It's hard to believe that ▶

> “Although no origin of the Solar System theory is a certainty, it's Laplace's model that prevails today, albeit in a modified form”

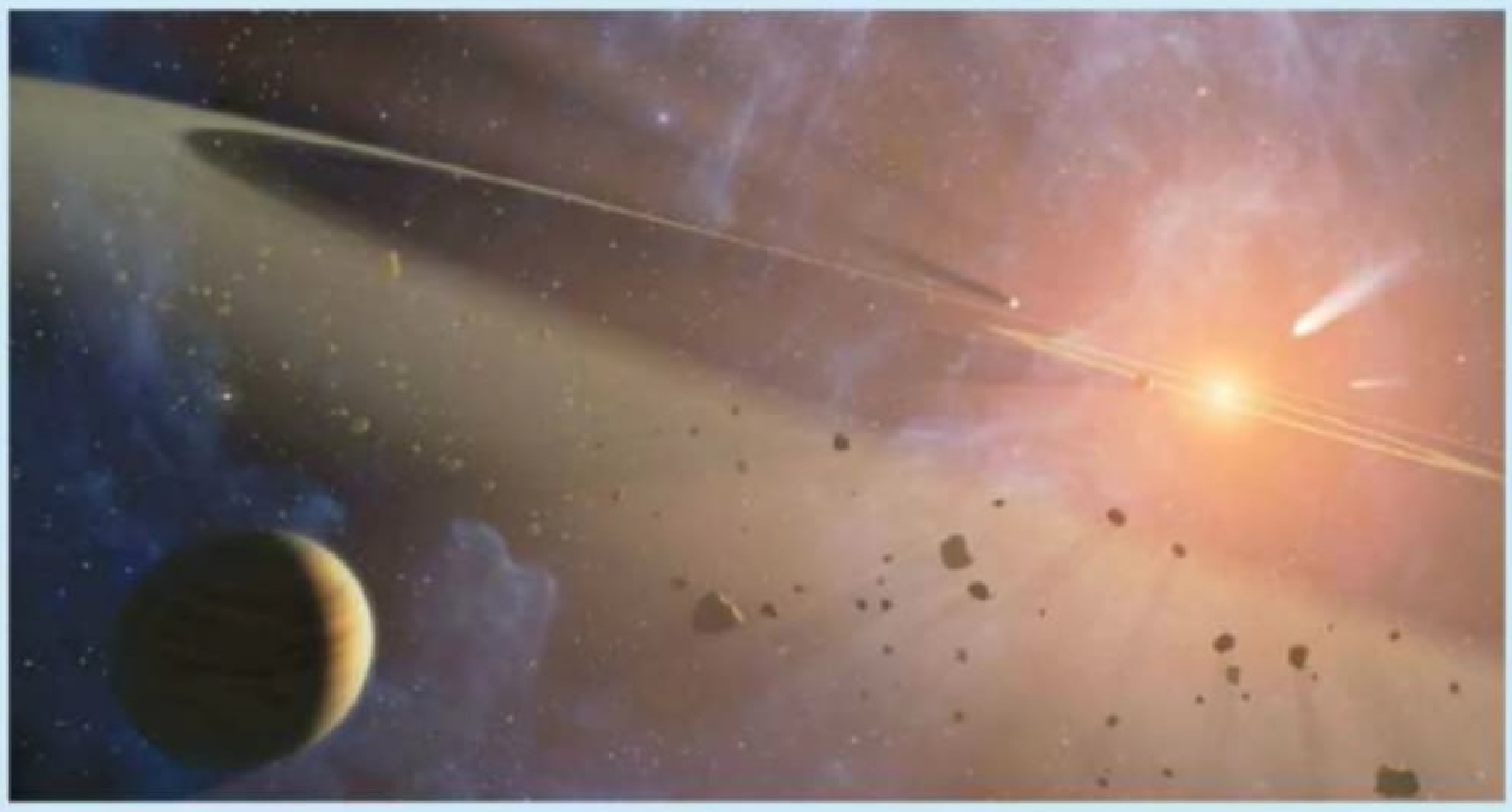
Planets on the move

The position of each of the planets is no mere coincidence. The gravity of the growing planets within the gaseous disc that formed around the new Sun in the early Solar System perturbed the gas around them, either removing or adding angular momentum. The lower-mass terrestrial planets experienced a lower rate of migration than the four massive Jovian planets in the outer Solar System, although only very rarely does migration cause a planet to move outward rather than inward. Planetary migration is also affected by the gravity of other celestial bodies as well as heavy asteroid bombardment in the first billion or so years of Earth's existence.

How the planets arrived at their current locations isn't known for certain, but it's probable that the terrestrial planets of Mercury, Venus, Earth and Mars migrated inward to their current positions in the inner Solar System, while the Jovian giants led a more complicated dance, moving inward from ice-forming regions and then back out again. It explains why the Asteroid Belt contains both bone-dry and water-ice objects. It's certain too that while the planets are stable in their current configuration, an ageing Sun and a collision with the nearby Andromeda galaxy billions of years from now will see planetary orbits change and, in all likelihood, Earth's ejection from the Solar System.

What is the Kuiper Belt?

In 1992, the Kuiper Belt was discovered. Similar in form to the Asteroid Belt, it's around 4.5-7.5 billion kilometres (2.8-4.6 billion miles) from the Sun, is 20 times wider and contains up to 200 times more mass. Where the Asteroid Belt is composed of small rocky minerals and metals, the Kuiper Belt is made up mostly of chunks of frozen methane, ammonia and water ice. It's a remnant of the early Solar System and space scientists suspect some comets originate from here. Two moons – Saturn's Phoebe and Neptune's Triton – are also suspected to have been planetesimals from the Kuiper Belt. After Pluto was declassified to a dwarf planet in 2006, it became the largest-known feature of the Kuiper Belt, although it was only the second biggest dwarf planet after icy Eris, which is 27 per cent larger than Pluto.



© Alamy, NASA

these massive celestial bodies were originally nothing but gaseous dust, but this is believed to be the case.

As the protostar collapsed and its angular rotational speed increased, what was left of the dust concentrated around the equatorial region to form a circumstellar disc. When the protostar went nuclear to become our Sun, an enormous blast of solar wind spread the dust evenly across over 6 billion kilometres (3.7 billion miles) of space.

The inner planets of the Solar System (Mercury, Venus, Earth and Mars) were all formed from the material that spread across the first 400 million kilometres (250 million miles). At this range it was too hot for molecules like water and methane to condense, so only heavier minerals and metals like iron and nickel clumped together. Like the protostar that became the Sun, they bound as motes of dust before forming larger rocks and, over millennia, developed into planetesimals – the seeds that would become the first four rocky planets from the Sun. Because of the scarcity of these heavier elements (ie hydrogen, helium and oxygen make up 99 per cent of the Milky Way compared to iron's 0.1 per cent), these planets could not grow very large compared to the four outer planets, which total 99 per cent of the planetary mass orbiting the Sun.

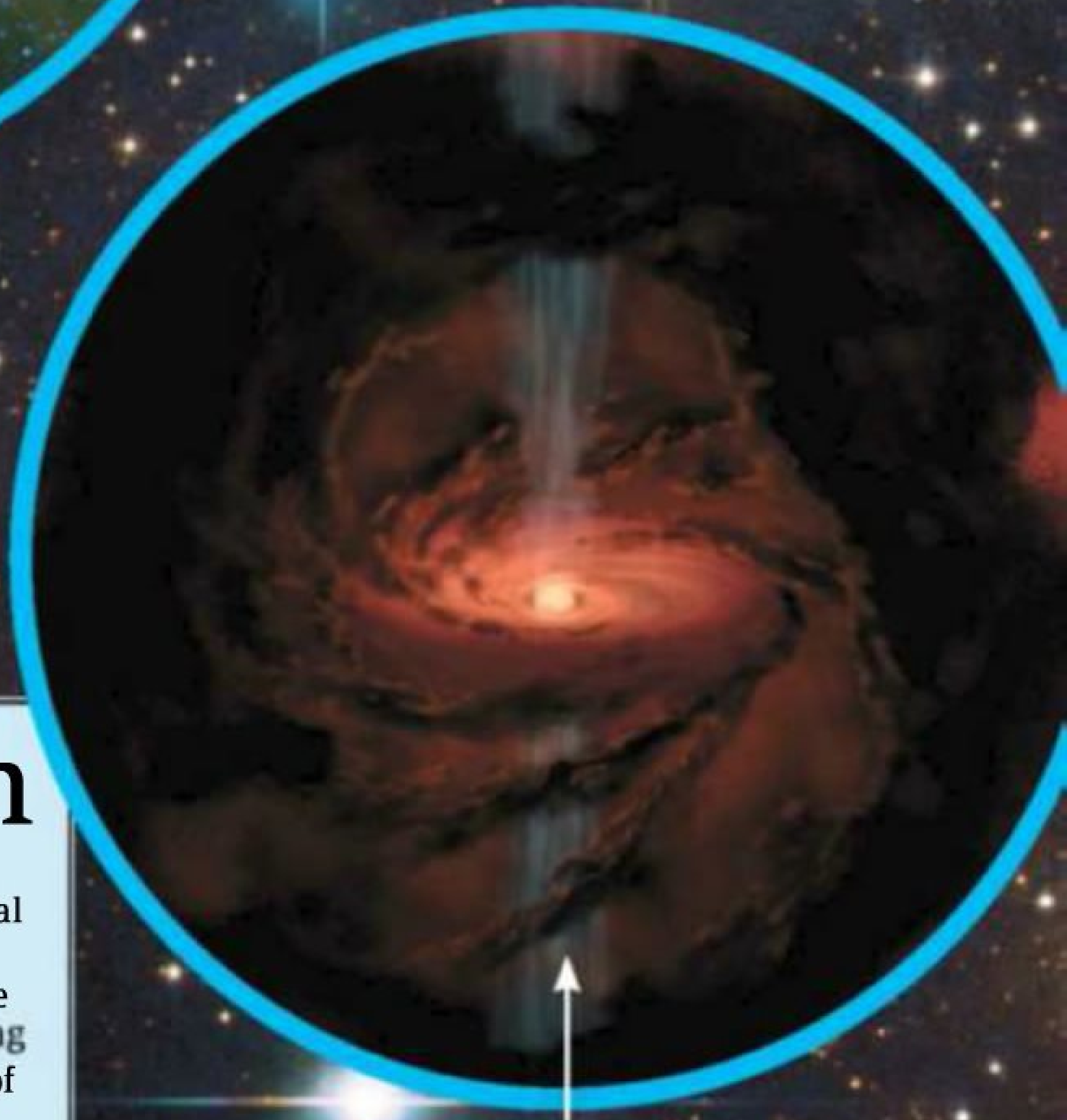
Between the inner and outer Solar System lies a vast strip of asteroids that was once believed to be a single planet that inhabited the orbital region between Mars and Jupiter, smashed apart by a colossal collision. At least, there seemed to be enough rocky mass to support the theory when German astronomer Heinrich Olbers proposed this idea in 1802. But since then, scientists have discovered not only that the Asteroid Belt would form a body only four per cent the size of Earth's Moon, but that the differing chemical compositions of the asteroids indicate they never came from a single body. Today, it's thought that the Asteroid Belt is simply a remnant of the original coalescing nebula, which was prevented from forming a planet by the mighty pull of nearby Jupiter's gravity.

Past the Asteroid Belt is the frost line. Here, at about 523 million kilometres (325 million miles) from the Sun and beyond, temperatures plummet to -120 degrees Celsius (-184 degrees Fahrenheit) – cold enough for gaseous compounds to solidify. There were enough of these volatile compounds to form giants Jupiter, Saturn, Uranus and Neptune. They grew massive enough to capture the lightest elements of helium and hydrogen, with Jupiter and Saturn taking the lion's share. By the time Uranus and Neptune had grown enough to hold onto the nebular gas, Jupiter and Saturn had claimed most of it.

We'll give an honourable mention to Pluto because for 76 years from the point of its discovery, it was considered a planet. However, due to finding many other similar-sized bodies orbiting the Sun – including the distant and super-icy Eris – it was reclassified as a dwarf planet. It's been suggested that Pluto was once an escaped moon of Neptune that was knocked out of its previous orbit by Triton, Neptune's current largest moon. It's now believed to be a member of the Kuiper Belt, which is similar in origin to the Asteroid Belt, only much bigger and located at the very fringes of the Solar System. ✿

The Solar System in the making…

1. Giant molecular cloud
A giant body of nebular particles begins to group together and, over time, forms larger and larger clumps.



2. Sun formation
The Sun forms from these clumps and throws off a massive coronal ejection that helps seed the planets.

Going for a spin

In astronomy, angular momentum is the amount of spin or orbital motion any celestial object possesses. It's calculated through multiplying mass by velocity by the distance from the object that celestial body is spinning around. It's a vitally important component of understanding the formation of our Solar System, because angular momentum dictated the initial spin of the molecular cloud that created the Sun and all of the planets. Thus, it played a major role in the initial distribution of the planets, their orbits and axial rotation. Ultimately, it had a huge hand in the form life took here on Earth.

Solar System timeline

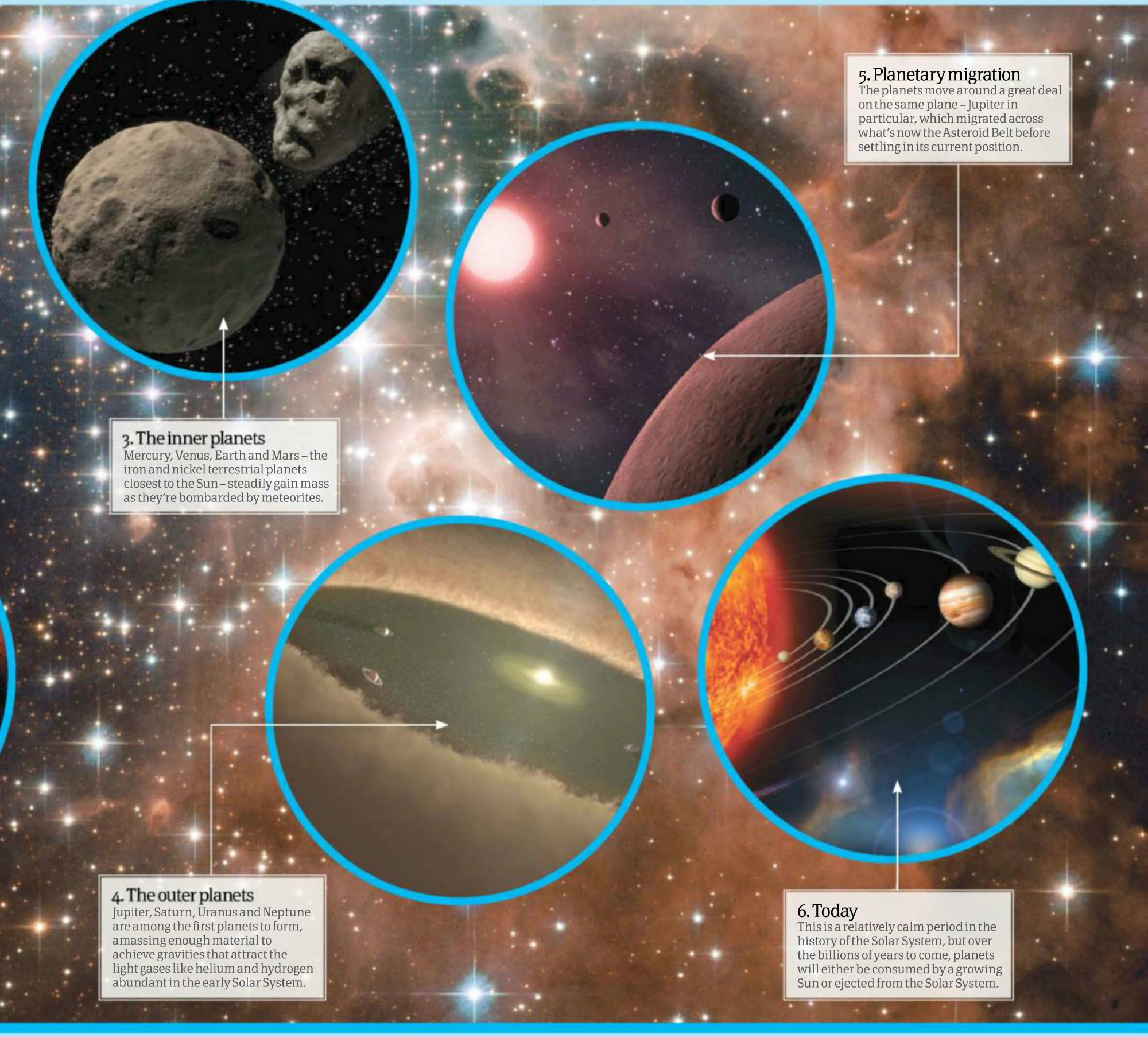
4.59
billion years ago
The Solar System forms as the Sun goes nuclear

4.3
billion years ago
Earth's satellite, the Moon, forms

2
billion years ago
Complex cellular life appears on Earth

Now
2012
Humans are the dominant species on our planet

1.5
billion years' time
The Sun expands; Earth is now uninhabitable



3. The inner planets
Mercury, Venus, Earth and Mars – the iron and nickel terrestrial planets closest to the Sun – steadily gain mass as they're bombarded by meteorites.

4. The outer planets
Jupiter, Saturn, Uranus and Neptune are among the first planets to form, amassing enough material to achieve gravities that attract the light gases like helium and hydrogen abundant in the early Solar System.

5. Planetary migration
The planets move around a great deal on the same plane – Jupiter in particular, which migrated across what's now the Asteroid Belt before settling in its current position.

6. Today
This is a relatively calm period in the history of the Solar System, but over the billions of years to come, planets will either be consumed by a growing Sun or ejected from the Solar System.

4.8
billion years' time
The Sun becomes a red giant

6.5
billion years' time
Saturn's moon Titan becomes habitable

10
billion years' time
The Sun sheds its outer gaseous layers

13
billion years' time
The Sun becomes a white dwarf

15
billion years' time
Life in the Solar System is now impossible

All images © NASA

What is an event horizon?

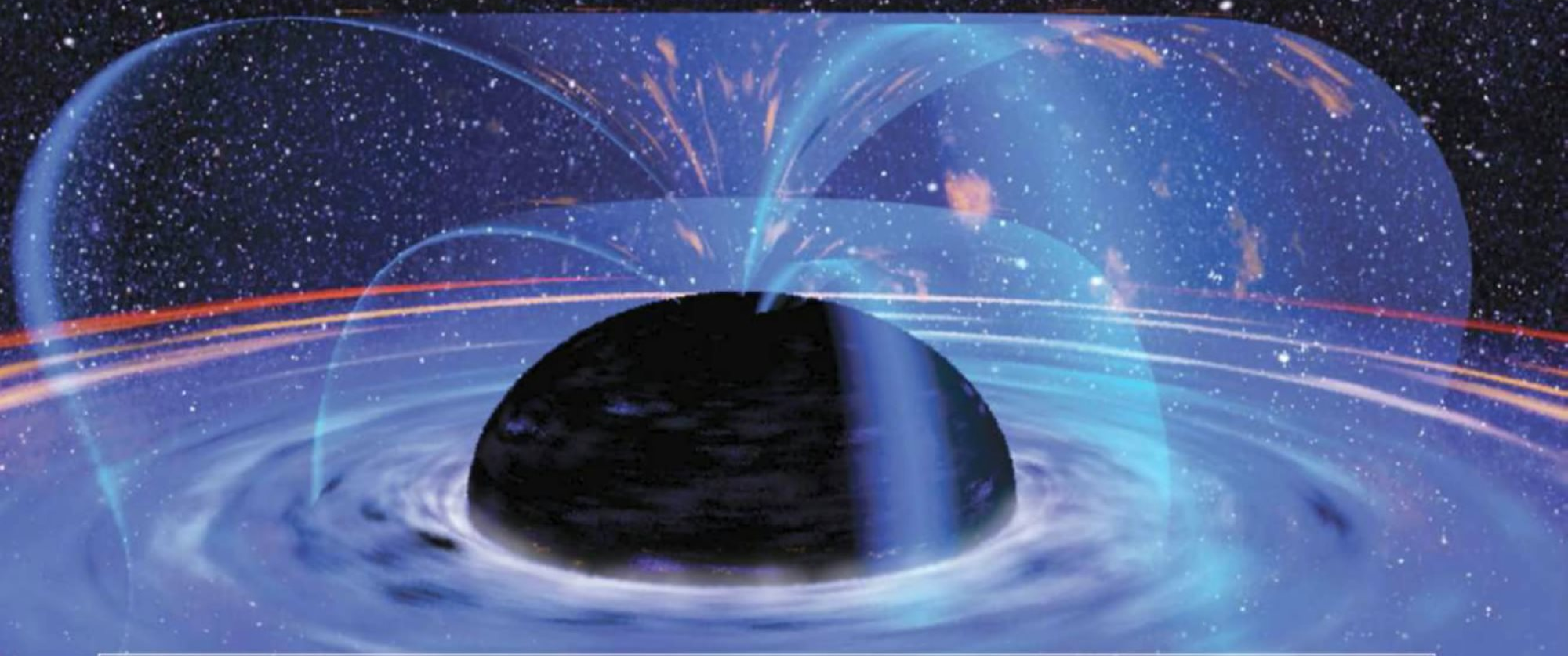
What makes these a black hole's point of no return?

There are three basic elements to a black hole explained by general relativity. There's the singularity itself, at the heart of a black hole and made of stellar matter compressed to an infinite density. Outside the singularity is the black hole's interior space, a region that's hard for even the most learned astronomers to imagine, where the rules of physics as we know them get bent and broken, and where space and time are stretched and compressed like putty.

If you've been zooming about interstellar space in your impossibly fast spacecraft, stumbled upon a black hole and entered its interior space, then it's already too late for you because you're past the third component of a black hole: its event horizon.

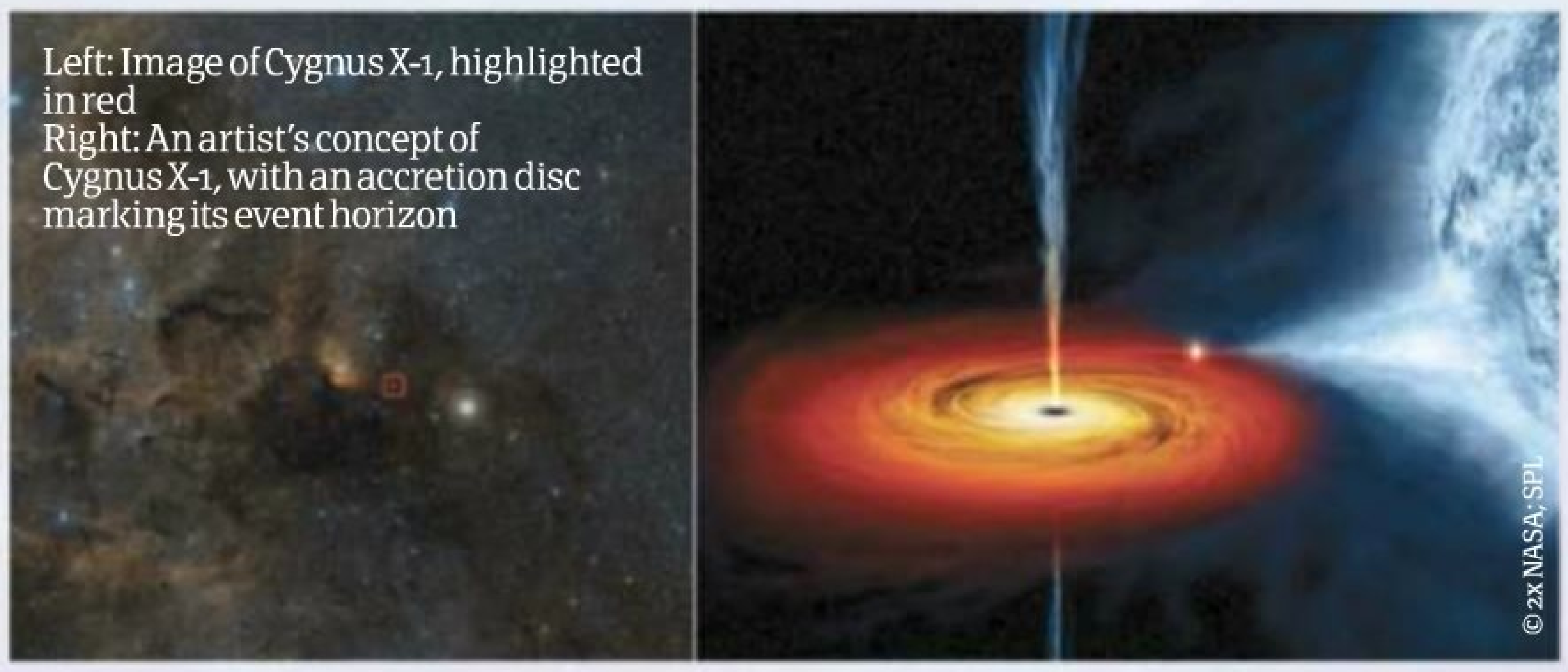
Also known as the Schwarzschild radius (after physicist Karl Schwarzschild), it's the part that lets us know where black holes are by outlining them in black. It marks the point of no return for anything falling beyond it, as to re-cross it would require travelling faster than the speed of light, which – as far as we know – is impossible.

Event horizons aren't solely attributed to black holes – they're just a noteworthy phenomenon that possesses them. According to some theories governing the expansion of the cosmos, there are areas that won't ever be observable because light will never reach us from them. So the boundary limit at which we can observe the universe is also referred to as an event horizon.



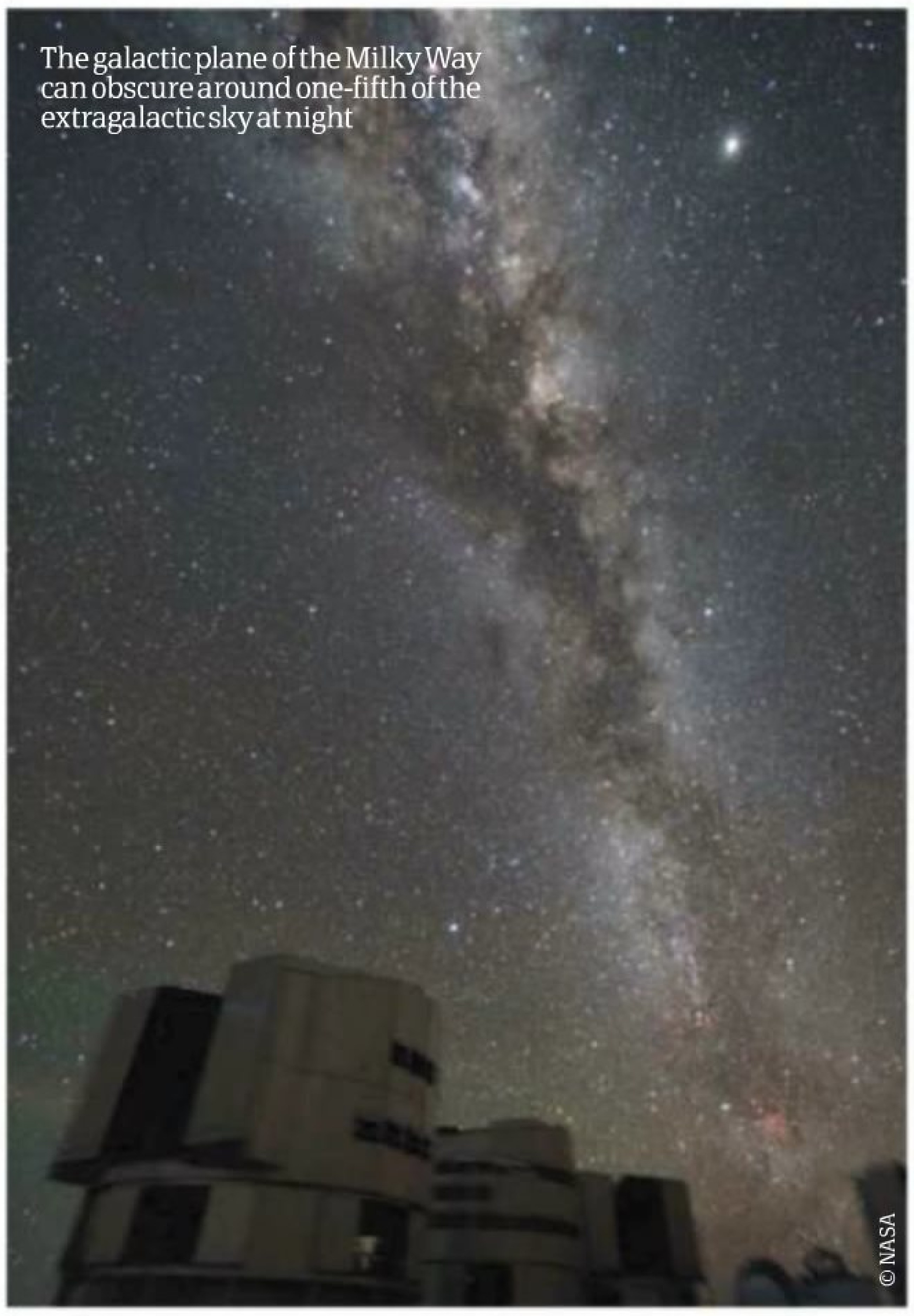
Accretion discs explained

Black holes are usually only detected when near another celestial body, such as Cygnus X-1 in the constellation Cygnus. Here, what used to be a pair of stars actually turns out to be a hot blue supergiant and the remnants of its former companion, which has devoured all its nuclear fuel and collapsed to become a singularity. The black hole is stripping the blue star of material, 'sucking' gas into it, which forms an accretion disc around the event horizon. This gas emits radiation on multiple wavelengths, including visible light and X-rays – 90 per cent of which is absorbed by the black hole. However, ten per cent is radiated away from the event horizon, enabling us to observe the accretion disc and estimate where the black hole is located.



Left: Image of Cygnus X-1, highlighted in red
Right: An artist's concept of Cygnus X-1, with an accretion disc marking its event horizon

© 2x NASA; SPL



The galactic plane of the Milky Way can obscure around one-fifth of the extragalactic sky at night

© NASA

Why does the Zone of Avoidance look so empty?

What is this region in space and why do stars – and even galaxies – appear to shun it?

The Zone of Avoidance (ZOA) is a narrow band in the night sky in which very few galaxies can be seen. To reflect this barren-looking region, astronomers nicknamed the band the 'Zone of Avoidance', as compared to other parts of the sky, celestial bodies seem to be actively avoiding this patch of space. Interestingly, however, the ZOA is actually a misnomer of sorts, as while it is true that very few galaxies are visible within it, it's not because they are not there, but rather that they are obscured by the interstellar matter of our own galaxy, the Milky Way.

This occurs as the interstellar dust, attenuation (loss of flux intensity) and stars in the plane of the Milky Way obstruct around 20 per cent of the extragalactic sky at visible wavelengths. As a result, this combination of factors makes it difficult to discern cosmic phenomena accurately.

Recent developments in space astronomy have made good headway in exploring this part of the sky by employing surveys of it at longer wavelengths than visible light. At these wavelengths, attenuation is almost entirely eradicated, making probing the ZOA more viable.

What is a starburst galaxy?

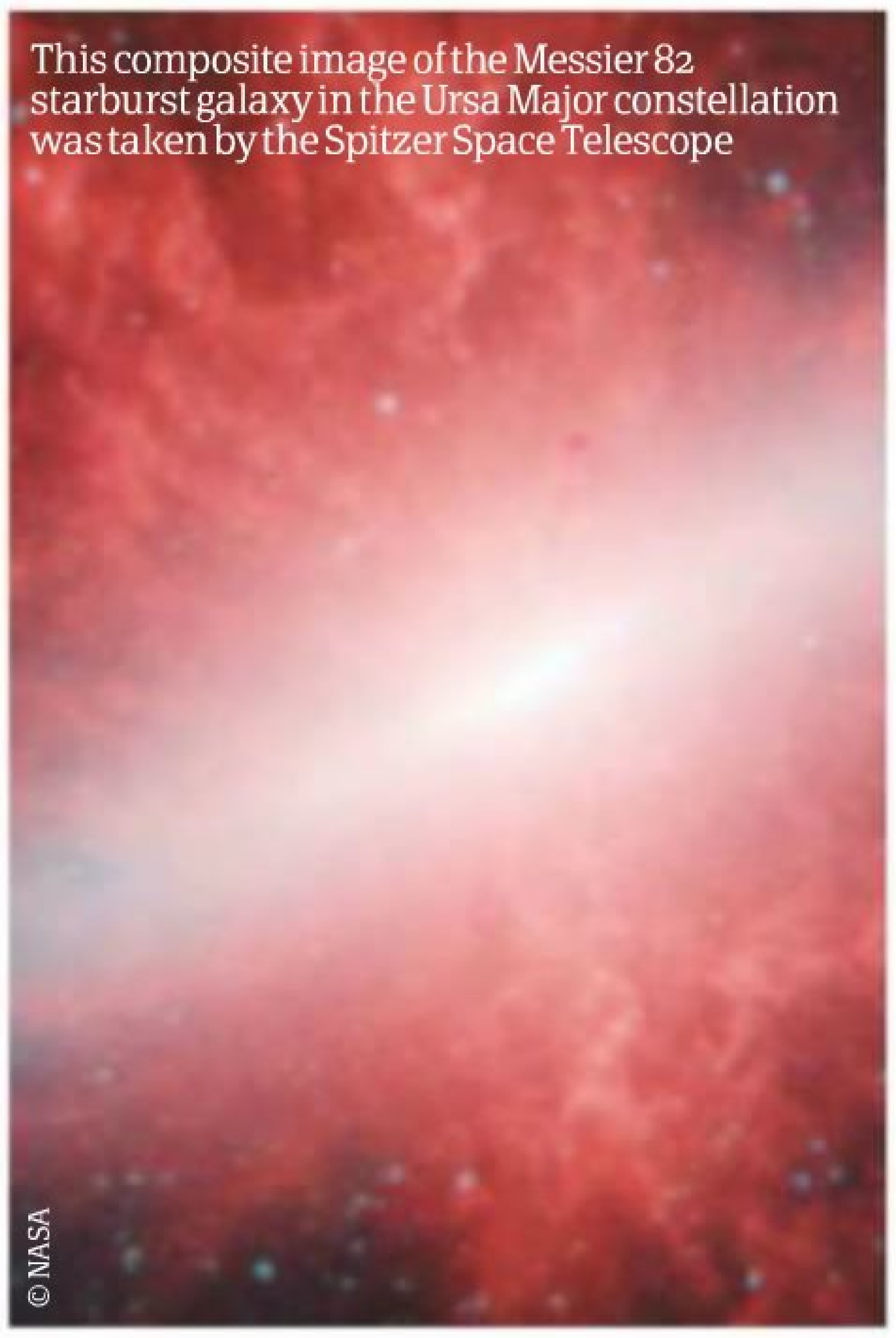
These galaxies produce stars much faster than anywhere else in the universe

A galaxy experiencing an unusually high level of star formation is commonly known as a starburst galaxy. This increased activity can often be so intense that stars only form for a period of approximately 10 million years, a tiny amount of time compared to the life of a 10 billion year old galaxy. With production at up to 100 times faster than a regular galaxy, the resultant stars are typically very massive and luminous.

These events usually occur when two galaxies collide, sending huge shockwaves out through the vast clouds of dust and gas within each individual galaxy and crushing them together to ignite the start of the incredible process of star formation.

The stars that are produced are often so massive that they use up their fuel extremely quickly, becoming supernovae and sending more shockwaves throughout the galaxy. This in itself creates a chain reaction of events until the available material in the galaxy is used up and the starburst eventually comes to an end.

> "This increased activity can often be so intense that stars only form for a period of approximately 10 million years"



This composite image of the Messier 82 starburst galaxy in the Ursa Major constellation was taken by the Spitzer Space Telescope

© NASA

The Cigar Galaxy, 11 million light years away, is the nearest starburst galaxy to Earth

© NASA

What is a dwarf planet?

What is a dwarf planet and how is it distinguished from other celestial bodies?

When is a planet not a planet? Well, it's not as simple as you might think. Defining a planet into a particular category isn't easy, with the debate continuing to rage as to how exactly planets should be classified. According to the International Astronomical Union (IAU), dwarf planets are spherical objects in orbit around the Sun that are not moons, but they share their orbits with other debris which they have not been able to clear. It was the latter point that let Pluto down back in 2006, as it has other bodies within its orbit that it has not gathered. In addition, many bodies were discovered that were larger than Pluto, such as Eris, ultimately leading to its reclassification.

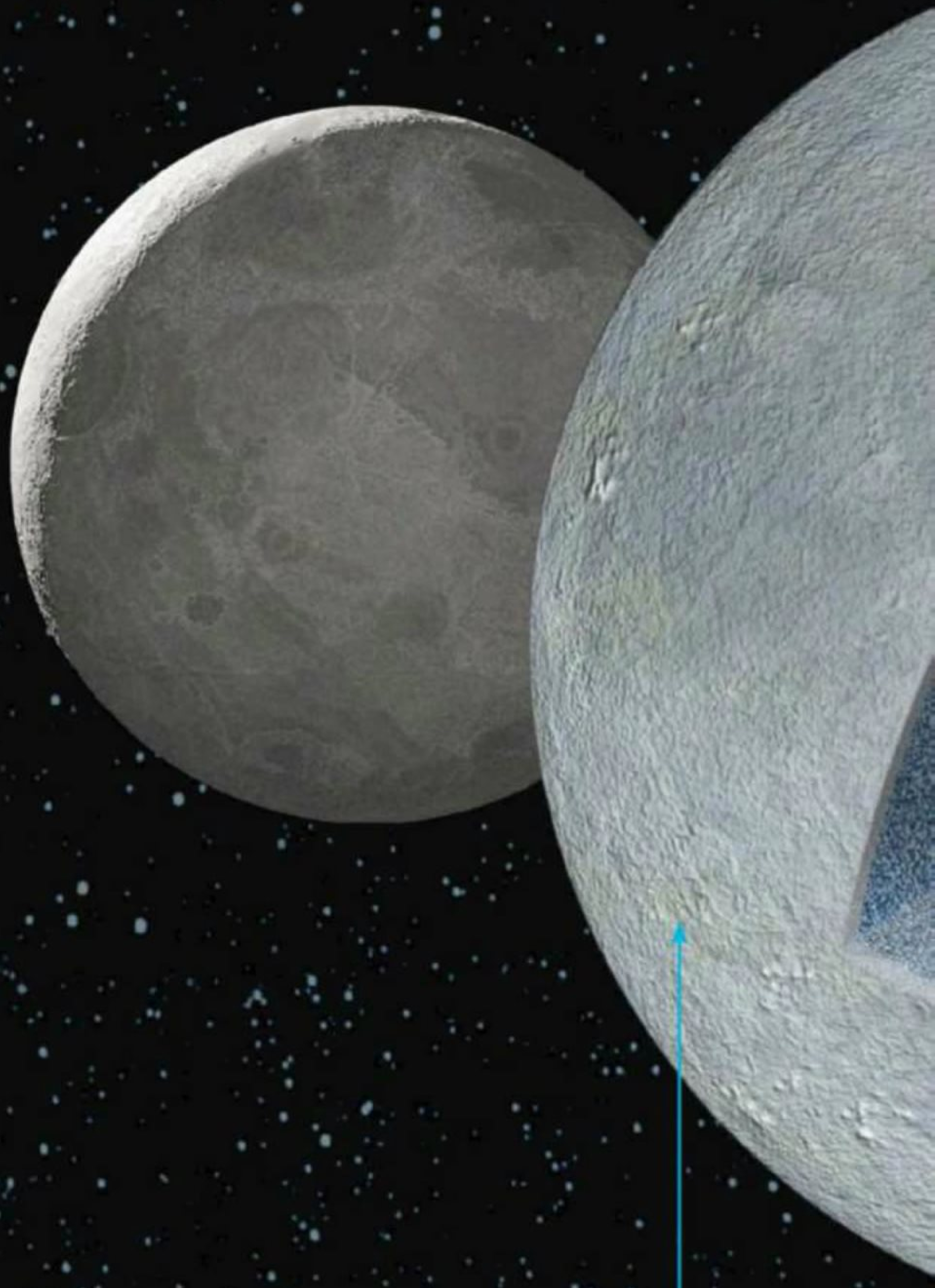
In simple terms, a dwarf planet can be regarded as a spherical object in our solar system exhibiting all or some of the properties of a planet, but lacking the necessary gravitational strength to have pulled other local objects into its influence.

There are currently five recognised dwarf planets in our solar system – these being Pluto, Eris, Makemake, Haumea and Ceres – but dozens more in the Kuiper belt, a disc-shaped region beyond Neptune, and the Oort cloud at the outer edge of the solar system, are being considered as candidates.

The five official dwarf planets and their unofficial brothers vary drastically in both composition and appearance, just as the main eight planets of the solar system do. Pluto is the only one of the five known to have its own moon – Charon, while Eris is the coldest of the bunch (and, indeed, the coldest known object in the solar system), with its surface temperature reaching as low as -250 degrees Celsius (-418 degrees Fahrenheit).

Also of note is the dwarf planet Ceres. Ceres was once regarded as a large spherical asteroid after research and redefinitions of celestial objects, it was recently promoted to a dwarf planet. Despite being the smallest dwarf planet, it is the largest object in the asteroid belt between Mars and Jupiter where it resides. Ceres' size accounts for about a quarter of the mass of the asteroid belt in our solar system. ✽

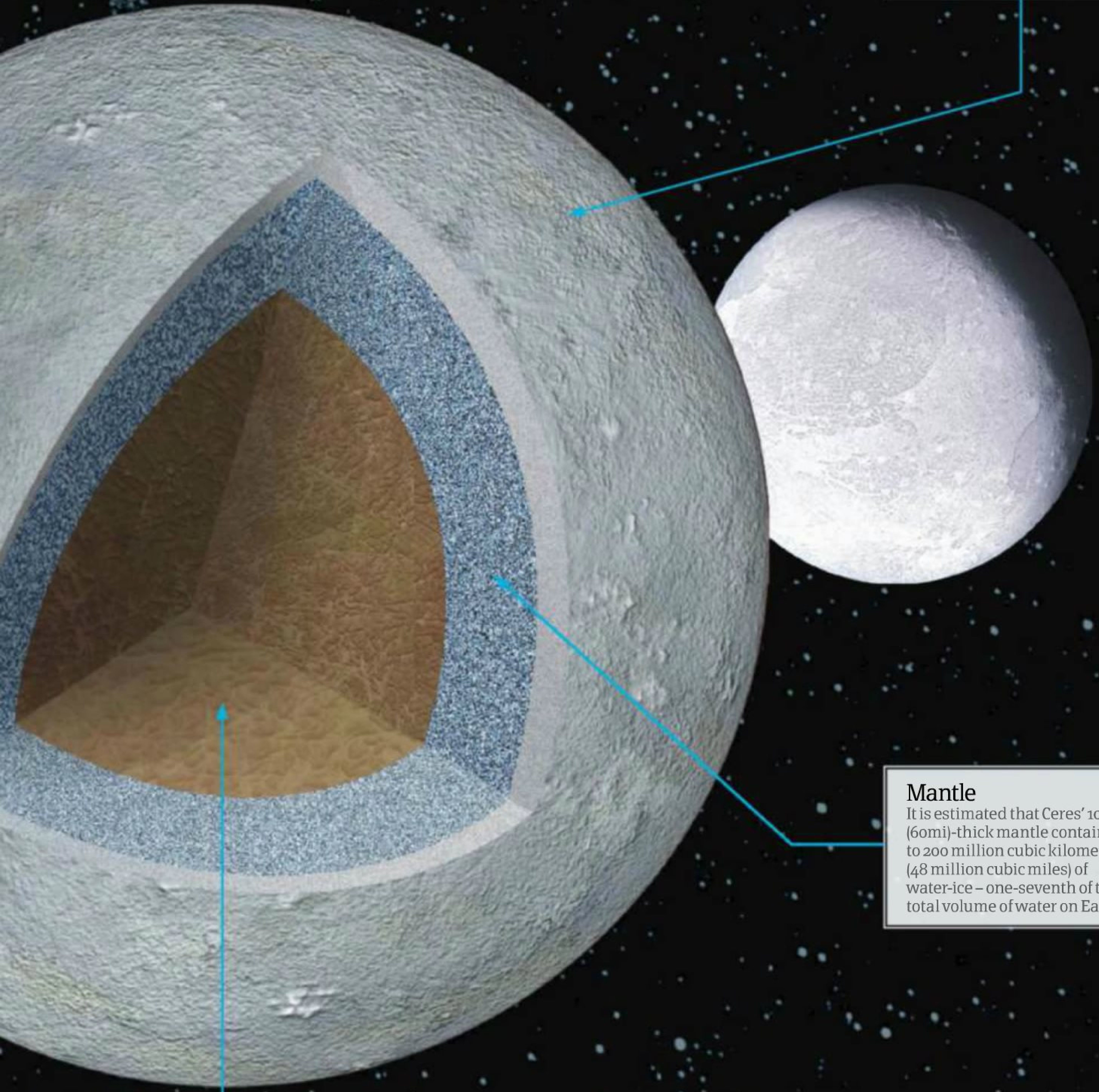
> "There are dozens more dwarf planets in the Kuiper belt beyond Neptune and the Oort cloud at the outer edge of the solar system"



Size
Ceres has a diameter of 942km (585mi), which is just over one-quarter the size of our moon.

Inside Ceres

What's going on within the smallest dwarf planet in our solar system?



Surface
Ceres' surface bears marks of previous meteorite impacts and, despite having only a thin atmosphere, its surface temperature is about -38°C (-36°F) due to it being relatively near to the Sun, almost three times Earth's distance from the Sun.

Mantle
It is estimated that Ceres' 100km (60mi)-thick mantle contains up to 200 million cubic kilometres (48 million cubic miles) of water-ice – one-seventh of the total volume of water on Earth.

Core
Ceres has a solid rocky core. It is thought that it may once have had a hot and molten core like that of Earth, but its small size means it is unlikely that volatile material is still present due to its high rate of heat loss.

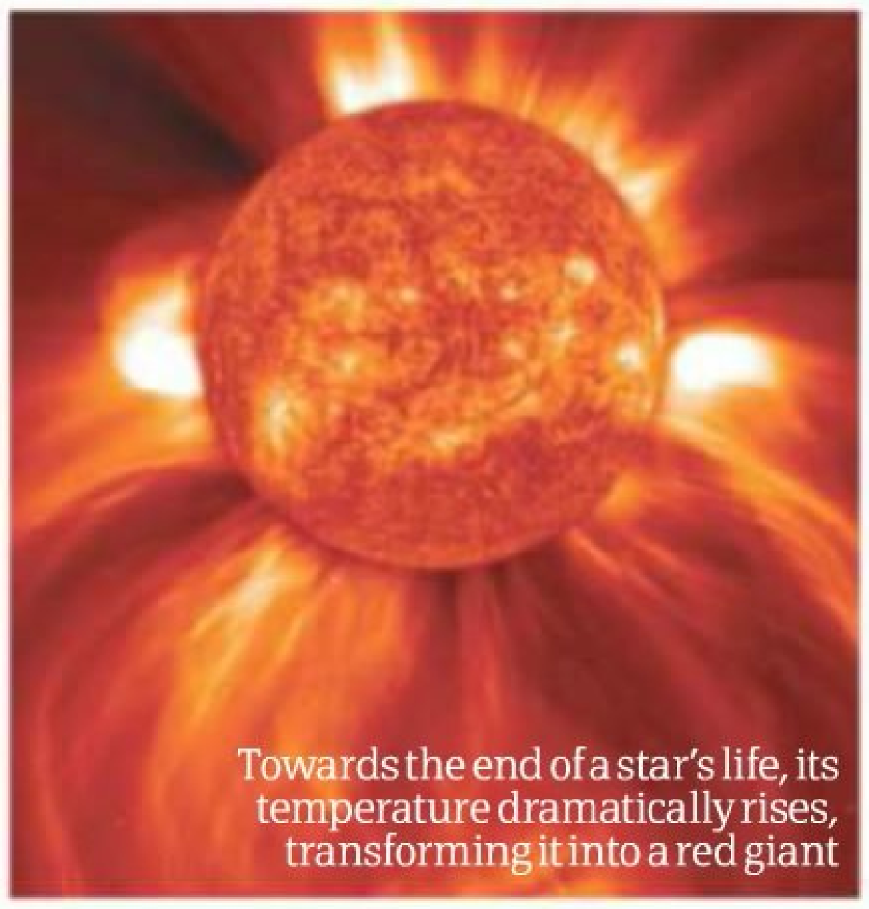
Why do stars turn blue?

These red giants got blue about being old…

While scanning our spiral neighbour – the Andromeda galaxy, 2.54 million light years away – the Hubble Space Telescope detected a group of bright blue spots near to the galactic nucleus. There is nothing unusual in that – blue spots are a fairly common sight, indicating young, hot supergiant stars. NASA was, however, surprised to see their ultraviolet light in this region of space and even more surprised to discover that they were dimmer and had a range of surface temperatures that didn't match the profile of infant stars.

In fact, these are rare ultra-blue stars – old red giants that are past their prime and have ejected most of their surface material out into space to expose their hot blue cores. This much ejection is unusual and likely happens because these stars are richer in certain chemical elements other than the normal helium and hydrogen, which makes it much easier for the star to slough off more layers into space. Another hypothesis is that the proximity of these stars to their binary partners makes it easier for them to shed more of their mass because of the gravitational influence.

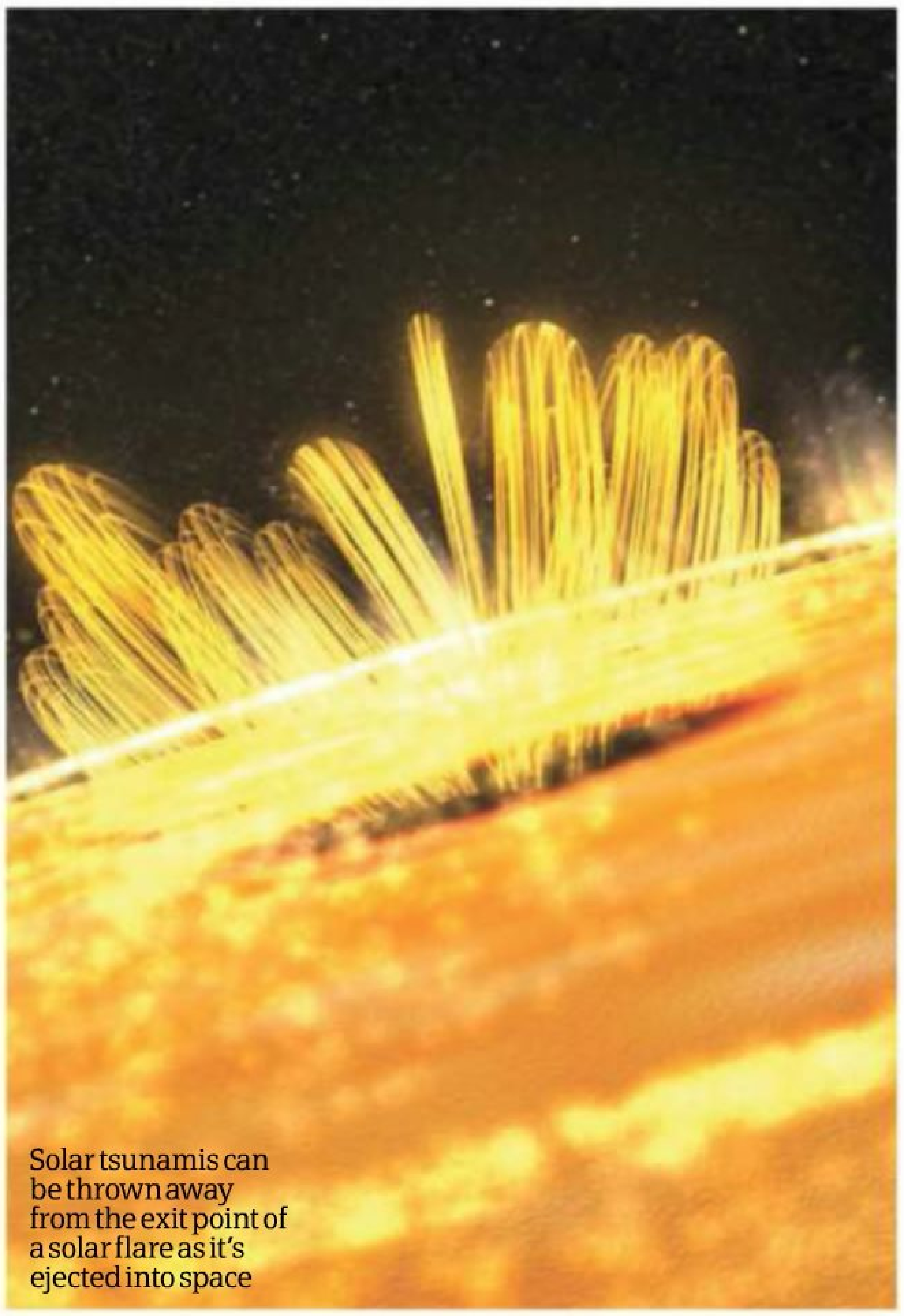
> “Their surface temperatures didn't match the profile”


Towards the end of a star's life, its temperature dramatically rises, transforming it into a red giant

In this area of the Andromeda galaxy, once red giant stars have consumed most of their fuel, the blue inner cores are all that remain

How are solar tsunamis caused?

The mega-waves of energy that tear from one end of the Sun to the other


Solar tsunamis can be thrown away from the exit point of a solar flare as it's ejected into space

Solar tsunamis – also known as Moreton waves or fast-mode magnetohydrodynamic (MHD) waves – are surges of material that are sent crashing across the Sun as the result of a solar flare being launched into space. They can travel at speeds up to 1.6 million kilometres (1 million miles) per hour.

These solar tsunamis are made of hot plasma and magnetic energy. The first was observed by Gail Moreton in 1959, and since then several more studies have been conducted on the phenomenon by the Solar and Heliospheric Observatory (SOHO) and also by the Solar Terrestrial Relations Observatory (STEREO) spacecraft, both of which orbit the Earth.

The solar tsunamis are formed when the Sun emits a coronal mass ejection (CME) – a massive burst of solar wind commonly associated with solar flares. Around the ejection point, a circular wave extends outwards in all directions and travels across the surface of the Sun at a super-fast rate.

In February 2009, the two STEREO spacecraft watched as a billion-ton cloud of gas was hurled off the surface of the Sun from a CME. The result of this ejection was a massive solar tsunami that towered 100,000 kilometres (60,000 miles) high and which sped across the star's surface at about 900,000 kilometres (560,000 miles) per hour. Estimates indicate that it contained the same energy as 2.4 million megatons of TNT.

> “They can travel up to 1.6 million kph”

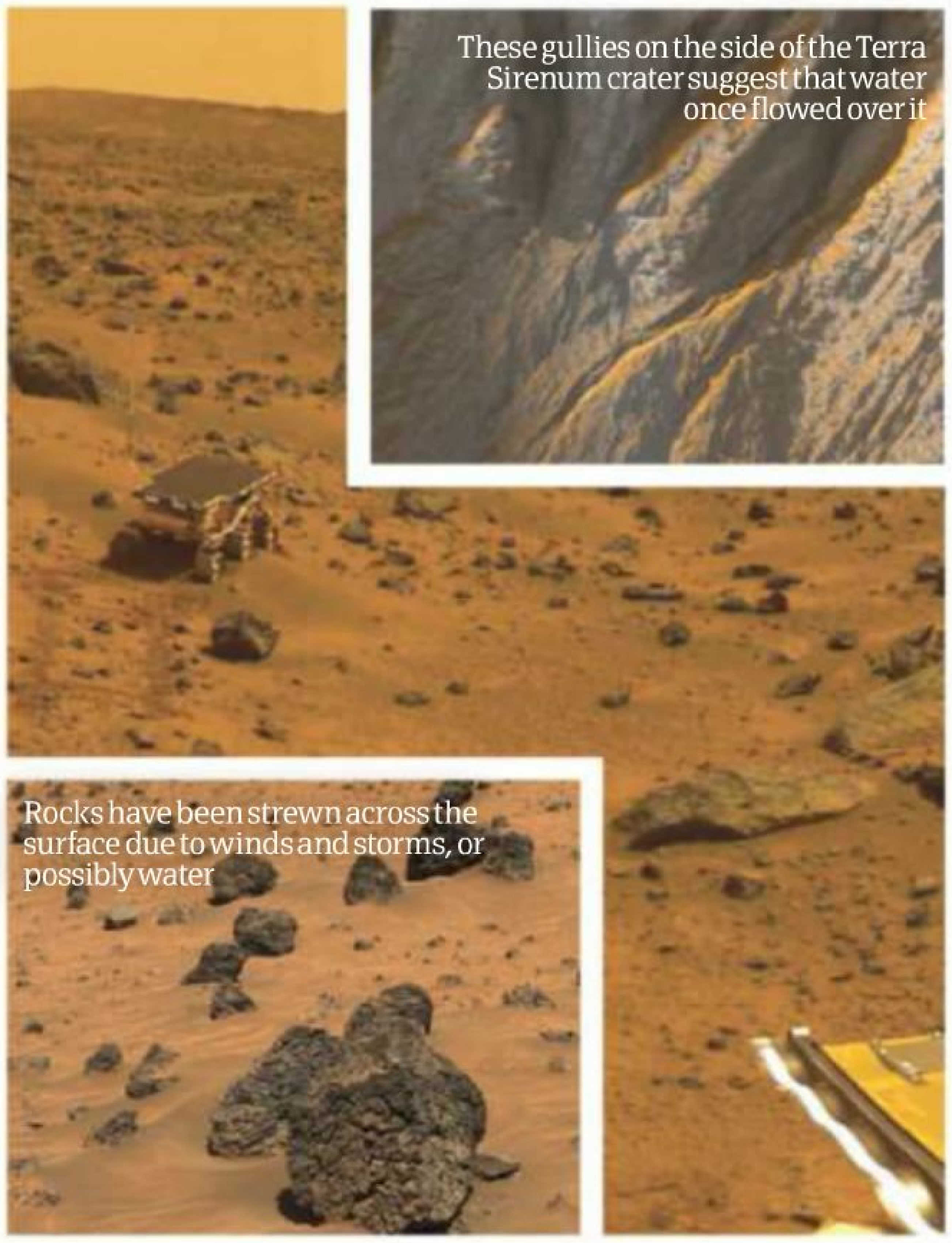
Why is the surface of Mars red?

How the red planet got its iconic colour

The red colour that we usually see in images of Mars is actually the result of iron rusting. Rocks and soil on the surface of Mars contained a dust composed mostly of iron and small amounts of other elements such as chlorine and sulphur. The rocks and soil were then eroded by wind and the resulting dust was blown across the planet's surface by the activity of ancient volcanoes. Recent evidence points to the very fine dust also being spread across the planet by water, a theory which is backed up by the presence of channels and ducts across the surface of Mars.

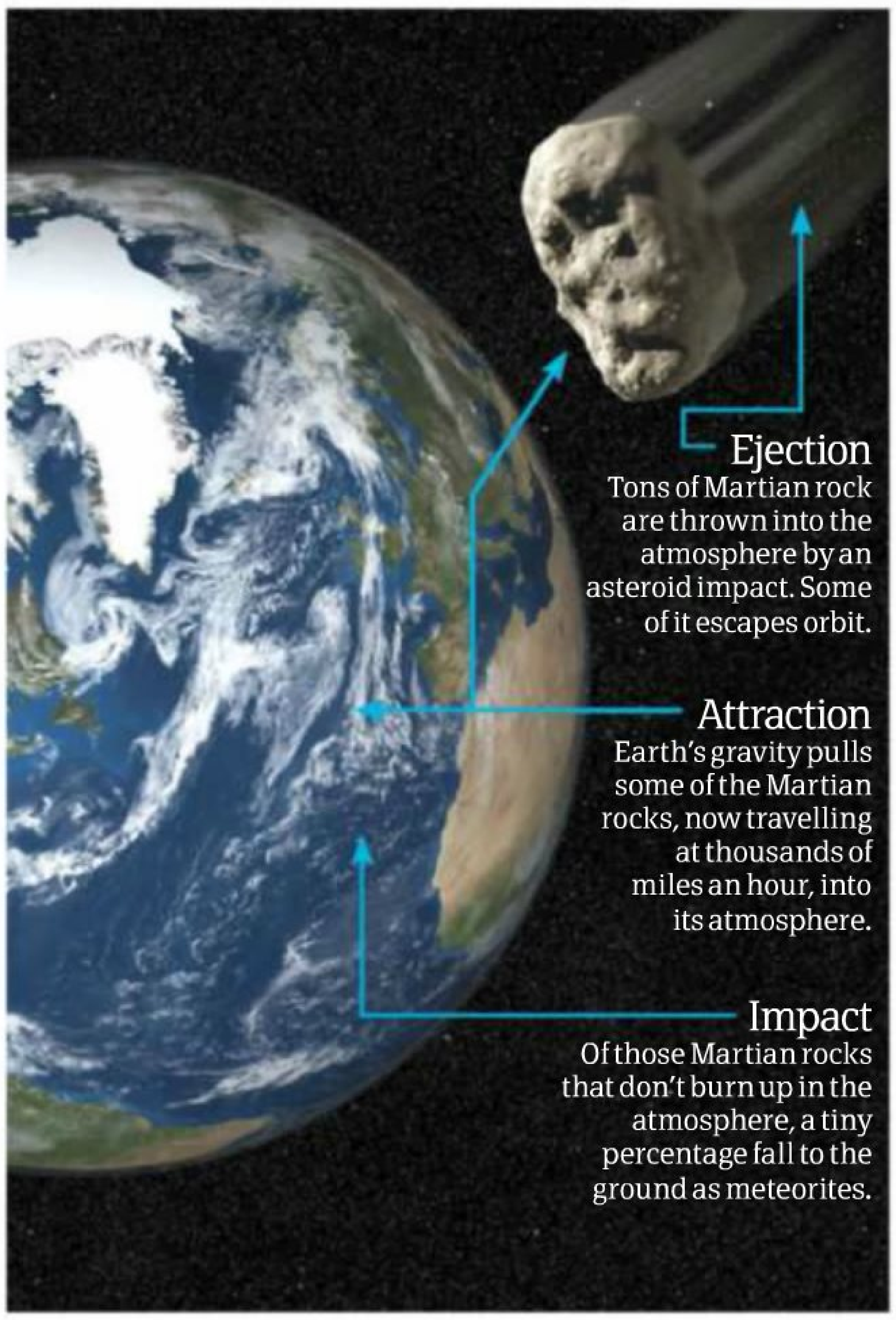
The iron contained within the dust then reacted with the oxygen in the atmosphere, producing the distinctive red rust colour, while the sky appears red because storms carried the red dust high up into the planet's atmosphere. This dusty surface, which is between a few millimetres and two metres deep, also sits above a layer of hardened lava which is mostly composed of basalt. The concentration of iron that is found in this basalt is much higher than it is in basalt on Earth, and this also contributes to the red appearance of Mars. No doubt the Curiosity rover will tell us more.

> “Storms carried the red dust high up into the atmosphere”



These gullies on the side of the Terra Sirenum crater suggest that water once flowed over it

Rocks have been strewn across the surface due to winds and storms, or possibly water


Ejection
Tons of Martian rock are thrown into the atmosphere by an asteroid impact. Some of it escapes orbit.
Attraction
Earth's gravity pulls some of the Martian rocks, now travelling at thousands of miles an hour, into its atmosphere.
Impact
Of those Martian rocks that don't burn up in the atmosphere, a tiny percentage fall to the ground as meteorites.

What are Martian meteorites?

How do these rocks from the red planet make their way over to Earth?

Martian meteorites are chunks of rock that have been churned up from our sister planet, Mars, usually as a result of an asteroid impact, and expelled from its gravitational sphere of influence. As you can imagine, they're pretty rare on Earth; in fact, only 61 of the 41,000 meteorites that have ever been discovered on this planet have been definitively identified as having come from the planet Mars.

The most recent confirmed meteorite from Mars to hit Earth has been named Tissint, and it's also the largest to date, weighing in at 1.1 kilograms (2.5 pounds). It was found in the desert in southern Morocco during the summer of 2011 and was classified as shergottite, a rock that came from somewhere within Mars's molten magma layer after an impact or expulsion by a volcano.

These meteorites are highly prized by scientists, who don't have any other practical way of analysing Martian rock samples (other than the Mars rovers). More importantly, Tissint can also provide clues as to the possibility of life on Mars; because it landed in a relatively lifeless area of Earth and was recovered quickly, any microfossils and Martian minerals altered by the presence of water will be relatively uncontaminated.

> “The most recent to hit Earth has been named Tissint”

Is the universe expanding?

Is the universe expanding and, if so, what will become of it?

The expansion of the universe was first theorised by Alexander Friedmann in 1922, who derived the Friedmann equations to show that the cosmos could be getting bigger. His theory was confirmed in 1929 by Edwin Hubble, who was the first to observe that distant galaxies appeared to be moving away from us.

Since then, it has generally been accepted that the universe is expanding. Some think that it will expand faster and faster, some think that it will reach a stable flat state and others believe it will eventually start to contract, culminating in a 'Big Crunch'. But what's for certain is that our observations clearly show that - for now - it is growing, and objects further away from us are moving faster than those that are closer.

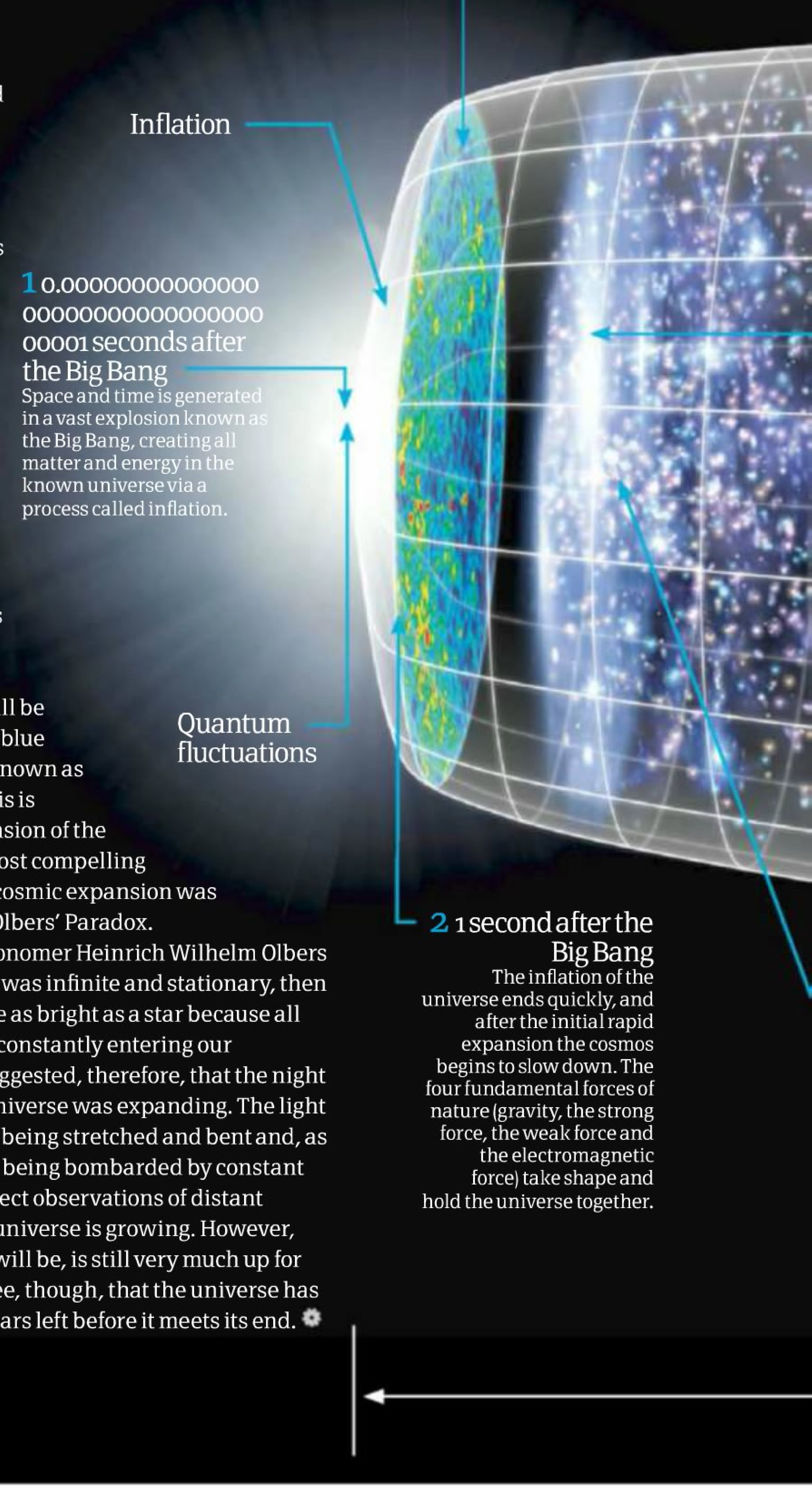
A good way to imagine cosmic expansion is in a smaller, more everyday scenario. Imagine that you have a deflated balloon, and on it you draw lots of dots. As you blow up the balloon all of the dots start to move away from one another, but there is no central point from which all the dots move. Indeed, dots further away from one another appear to move at a greater speed and dots closer to each other don't seem to move away from one another at the same speed.

This is essentially what is happening in the universe, but on an infinitely larger scale, with entire galaxies appearing to move away from one another. There is, however, no centre of the cosmos. In other words, if we stood on a planet in another galaxy, we would observe the same phenomenon as on Earth – namely that everything is moving away from us, with further objects moving more rapidly.

Every galaxy has something known as red shift, which is the primary method through which the expansion of the universe was confirmed. This can be best explained by comparison to the Doppler effect. When a police car drives past you with its siren on, the sound waves are compressed and subsequently expanded as it zooms by. As it comes towards you the sound waves are squashed, while as it moves away the waves are stretched. This decreases and increases the frequency of the sound waves, respectively.

The same thing happens with light coming from a distant galaxy. As the galaxy is moving away from us, the light from it appears to stretch towards the red end of the electromagnetic spectrum. The further away – and thus the faster a galaxy is moving from us – the greater the red shift will be. As an aside, if a galaxy is spinning, the side moving towards us, will be squashed towards the blue end of the spectrum, known as blue shift, although this is unrelated to the expansion of the universe. One of the most compelling pieces of evidence for cosmic expansion was something known as Olbers' Paradox.

In 1823 German astronomer Heinrich Wilhelm Olbers posited if the universe was infinite and stationary, then the night sky should be as bright as a star because all stellar light should be constantly entering our atmosphere. Olbers suggested, therefore, that the night sky was black as the universe was expanding. The light from distant stars was being stretched and bent and, as a result, Earth was not being bombarded by constant light. Coupled with direct observations of distant galaxies, it's clear the universe is growing. However, what its eventual fate will be, is still very much up for debate. Scientists agree, though, that the universe has more than a million years left before it meets its end. ✲



1 0.00000000000000 00000000000000000 00001 seconds after the Big Bang
Space and time is generated in a vast explosion known as the Big Bang, creating all matter and energy in the known universe via a process called inflation.

2 1 second after the Big Bang
The inflation of the universe ends quickly, and after the initial rapid expansion the cosmos begins to slow down. The four fundamental forces of nature (gravity, the strong force, the weak force and the electromagnetic force) take shape and hold the universe together.

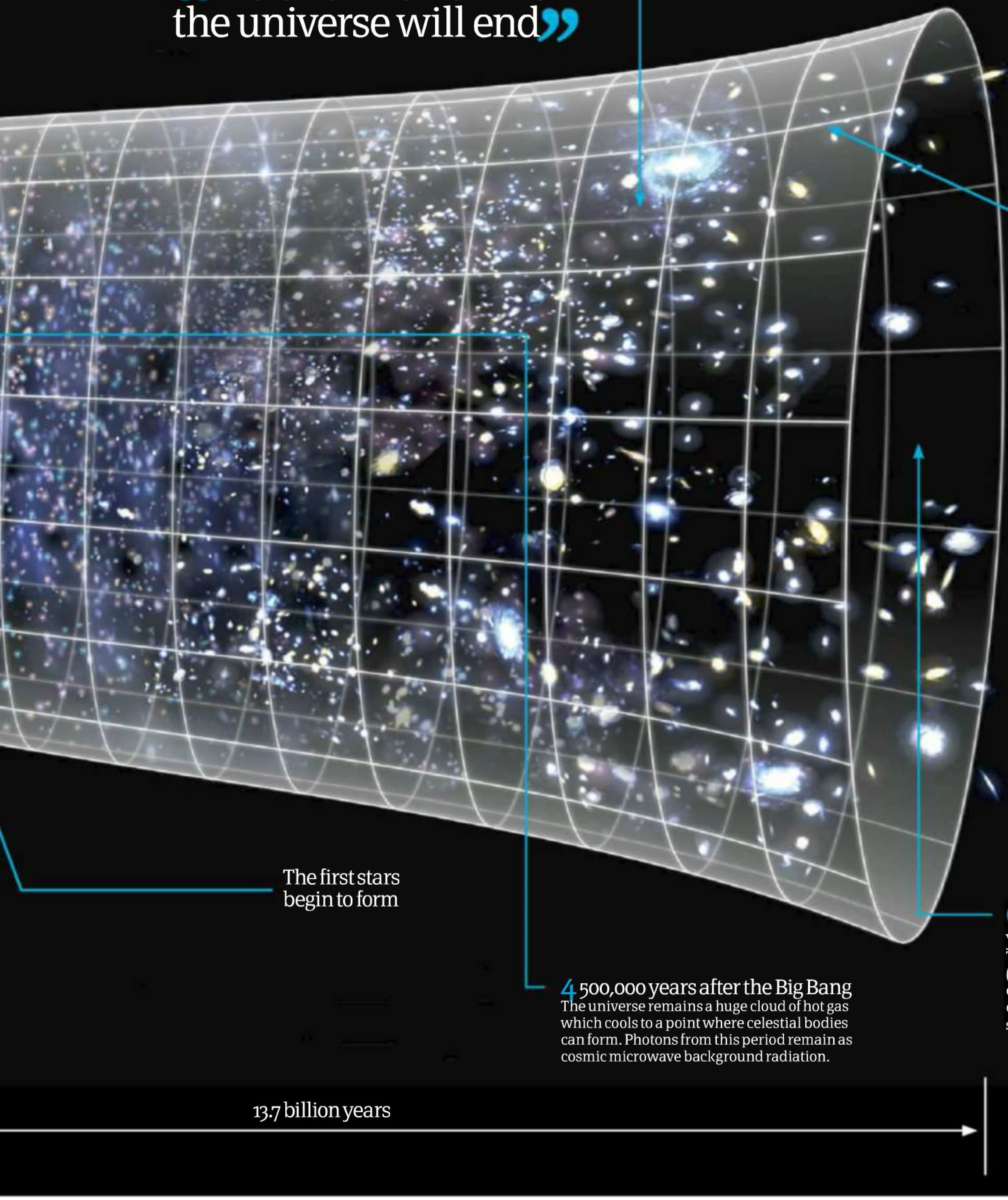
3 3 minutes after the Big Bang
The universe as we know it begins to take shape. Protons and neutrons come together to form basic matter and elements – mostly hydrogen and helium.

The evolving universe

What's happened since the Big Bang?

> "No one knows when the universe will end"

5 **1 billion years after the Big Bang**
The gravitational pull of matter in the universe draws together clouds of primordial gas. This gas becomes more and more dense until a new wave of stellar ignition occurs, producing stars and ultimately galaxies, which comprise many other celestial bodies formed by gravity.


Dark energy accelerated expansion
The first stars begin to form
13.7 billion years

4 **500,000 years after the Big Bang**
The universe remains a huge cloud of hot gas which cools to a point where celestial bodies can form. Photons from this period remain as cosmic microwave background radiation.

6 **Present day (13.7 billion years after the Big Bang)**
The universe has cooled to 2.7 Kelvin (-270°C/-455°F) but continues to expand. It is unknown if it will continue to grow forever, become stable or eventually contract.

© ESO

What is the Carina Nebula?

Relatively close to Earth, thousands of new stars are being born. Read what leads to their formation and where this unique phenomena is taking place on a huge scale

The Carina Nebula is - astronomically speaking - close to the Earth at only 7,500 light years away. It was formed 3 million years ago and, far from being an inert cloud, it contains over 14,000 stars, with this figure in constant flux. Evidence points to the fact that supernova explosions are on the up in the region and new stars are being born all the time. Stars are conceived when gravity gathers up molecules of the nebula gas, packing them tightly together and increasing the temperature. The cloud begins to rotate faster and the core reaches around 10,000 Kelvin (9,700 degrees Celsius/17,500 degrees Fahrenheit) at which point hydrogen molecules have broken down into their component atoms and fusion reactions start. The cloud then becomes a protostar – 30 times the size of the Sun.

The protostar collapses further until core pressure and temperature is great enough to sustain nuclear fusion. At this stage the star is contained in a dust envelope, a kind of exhaust from the process of the star's gestation, making the star invisible to the naked eye. In time, pressure exerted by radiation blows the envelope away to reveal the new star.

This recent image from the ESO's Very Large Telescope (VLT) has revealed the Carina Nebula in unprecedented detail. The bright yellow star near the middle is Trumper 14, while the dark patches to the right are the dust envelopes disguising new stars. In the bottom-left is Eta Carinae; at around 100 solar masses, it is one of the biggest stars in the galaxy that radiates with 5 million times more power than our Sun. It's near the end of its life and is expected to go supernova in an astronomically short amount of time. In fact, some astronomers believe it could explode any time in the next millennium.

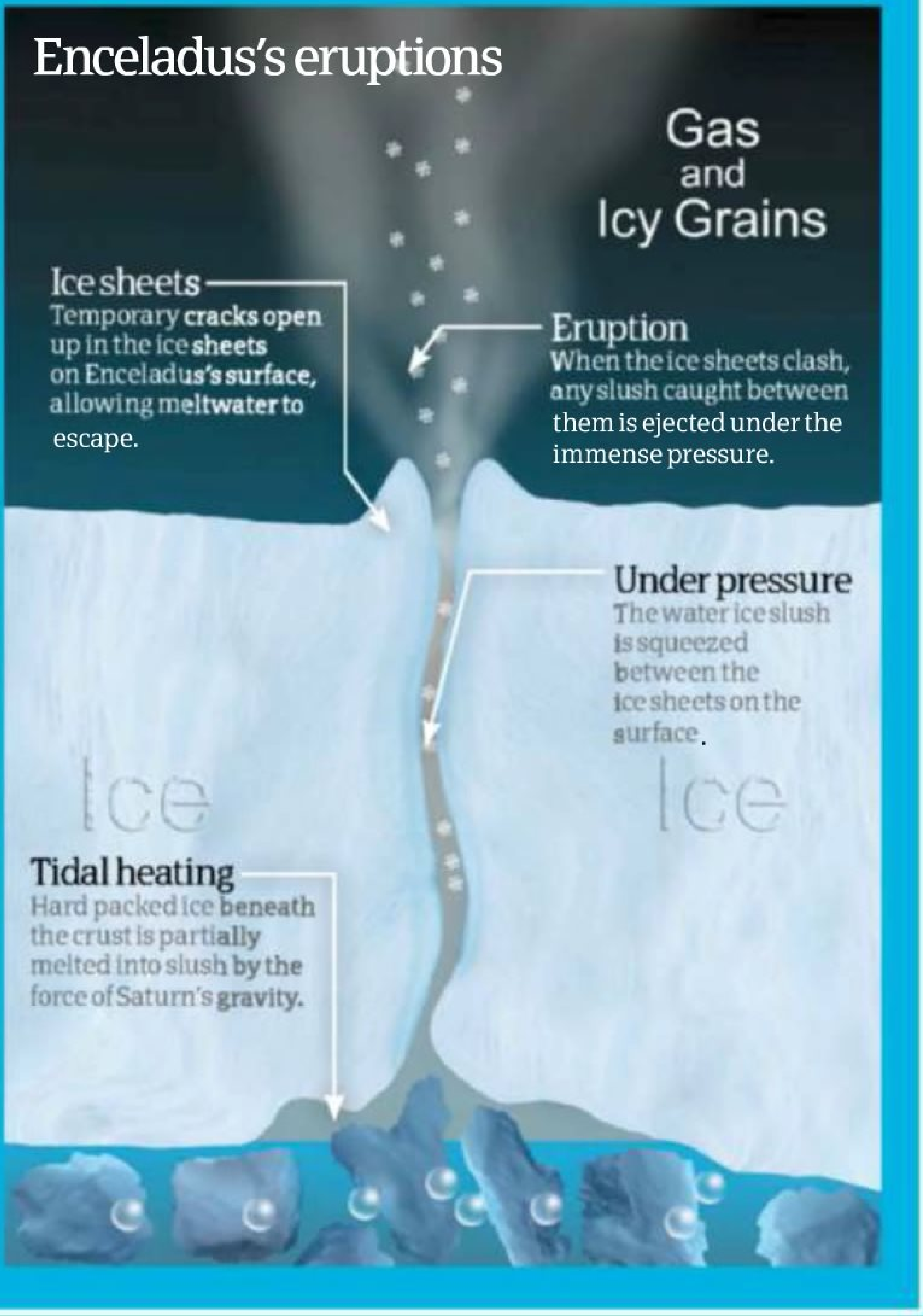
How do ice volcanoes form?

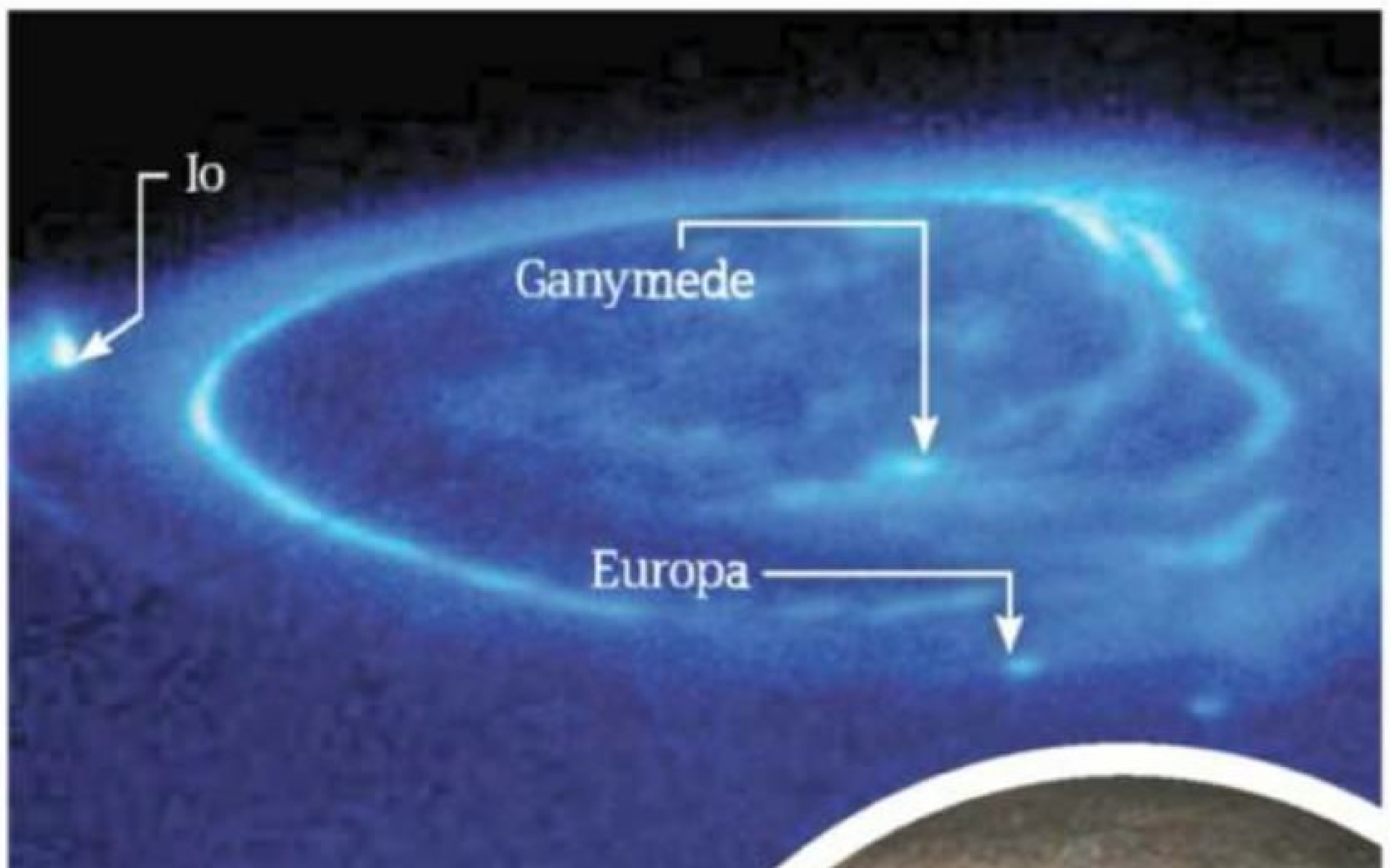
Saturn's freezing moon Enceladus has volcanoes, but they're not what you'd expect

They're known as cryovolcanoes, and though scientists don't have cast-iron proof that volcanoes spouting ice from a sub-zero caldera exist on Enceladus, there is strong evidence for it. The flyover by Cassini two years ago revealed jets spurting from four cracks along the moon's surface, named Alexandria, Cairo, Baghdad and Damascus. The eruptions were so high that they could easily be seen in profile from space.

Volcanoes found on Earth and also Jupiter's moon Io spout silicate lava that is heated by the pressure beneath the crust. Ice volcanoes work in a similar way: scientists believe that subterranean geological activity on Enceladus warms the freezing surface into a slush of water, ice and organic compounds, which is then ejected out by force through the surface by ice sheets grinding up against one another.

Enceladus has an elliptical orbit similar to our moon, so as Saturn's gravity pulls unevenly at Enceladus it creates a bulge that generates the friction and heat necessary to cause this previously unheard-of phenomenon.


Enceladus's eruptions
Gas and Icy Grains
Ice sheets
Temporary cracks open up in the ice sheets on Enceladus's surface, allowing meltwater to escape.
Eruption
When the ice sheets clash, any slush caught between them is ejected under the immense pressure.
Under pressure
The water ice slush is squeezed between the ice sheets on the surface.
Ice
Ice
Tidal heating
Hard packed ice beneath the crust is partially melted into slush by the force of Saturn's gravity.


Io
Ganymede
Europa

A more familiar shot of Jupiter, our solar system's largest planet

4x © NASA

What causes Jupiter's aurora?

What scientists saw within the gas giant's northern lights

Above is an image of Jupiter's aurora, taken by the Hubble Space Telescope in 1998. Auroras themselves aren't peculiar to Jupiter; they occur on Earth on both the North and South Poles and are called the aurora borealis and aurora australis, respectively.

Solar winds hitting the atmosphere and centring on the magnetic poles cause the phenomenon on Earth, but on Jupiter it's caused by the massive gas giant's own magnetic properties interacting with its upper atmosphere and exciting the gases that exist there, causing them to glow extremely brightly.

What makes this image particularly special is that you can also see the magnetic footprints of three of Jupiter's four largest moons within the Jovian auroral blue glow. Io, Ganymede and Europa's own auroras (which are labelled) show up as three blobs of light and the electric currents generated by these three satellites move along the magnetic field of Jupiter, bouncing in and out of its atmosphere.

This shot was taken from the ultraviolet part of the spectrum, so this particular perspective of the aurora cannot be observed with the naked eye. It shows the main oval centred on Jupiter's north pole.

> "You can also see the magnetic footprints of three of Jupiter's four largest moons"

Why does the Earth spin?

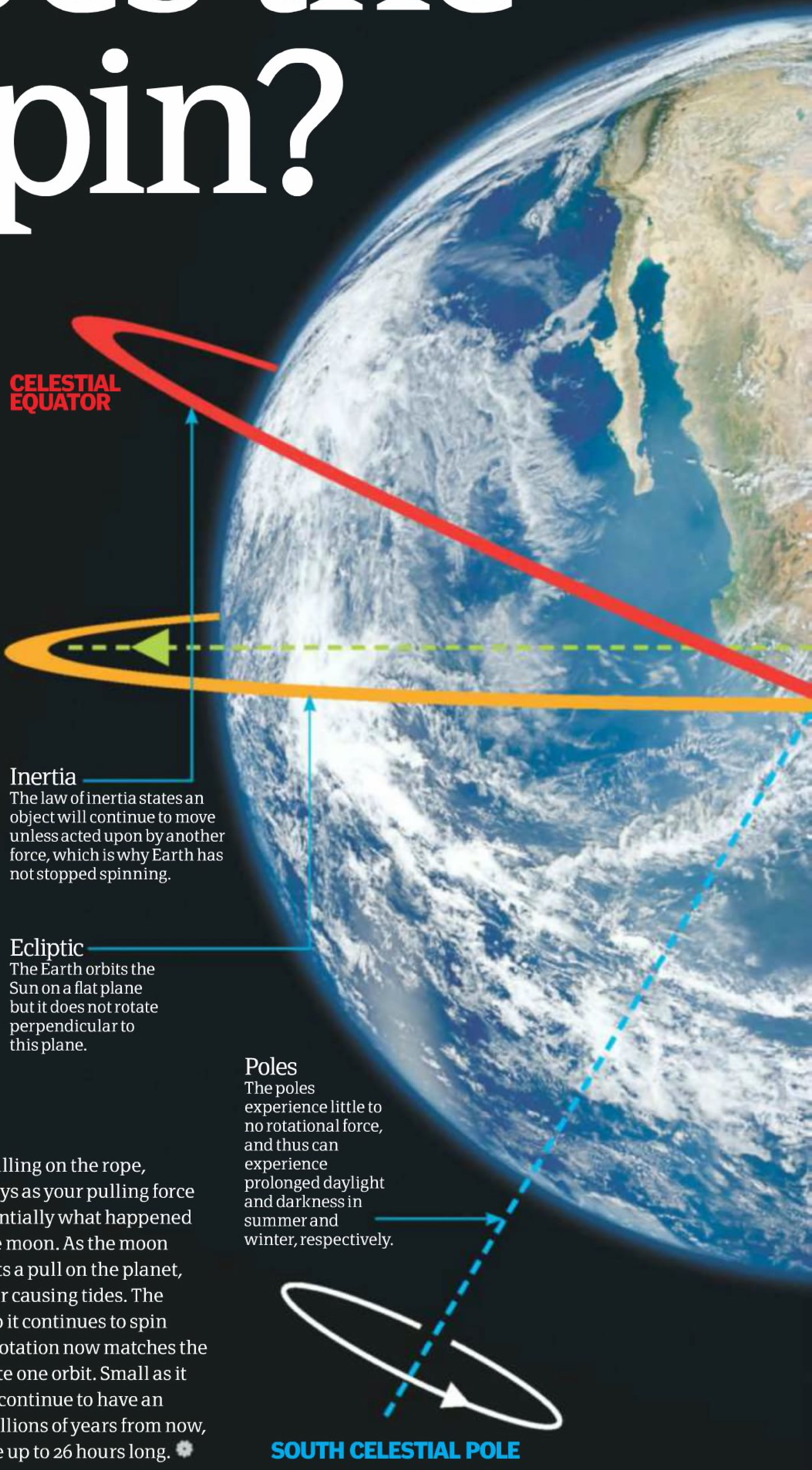
Find out why our planet has rotational movement

The story of why the Earth spins goes back to the formation of the solar system. In the beginning, roughly 4.7 billion years ago, the solar system was a large swirling cloud of dust and gas. Over time this gradually coalesced into stars and planets, being drawn into these shapes by gravity. This motion of being pulled inwards increased the angular momentum of the various bodies, and thus caused them to start rotating faster.

Consider an ice skater spinning with their arms outstretched. As they spin, they bring their arms inwards. Doing so increases their angular momentum, which makes them spin faster. The same is true for when the Earth first formed. As the dust and gas was compressed into one solid mass, the total mass of the object became more confined and subsequently began to rotate more and more rapidly.

The law of inertia states that anything stationary or moving with a constant speed wants to continue doing so until it is acted upon by another body/force. Considering the Earth rotates in space, which is a vacuum, there is nothing to drastically slow the Earth down, which is why it continues to spin. Interestingly, early in its formation, the Earth spun up to five times faster than it does now – so we know Earth has lost some speed.

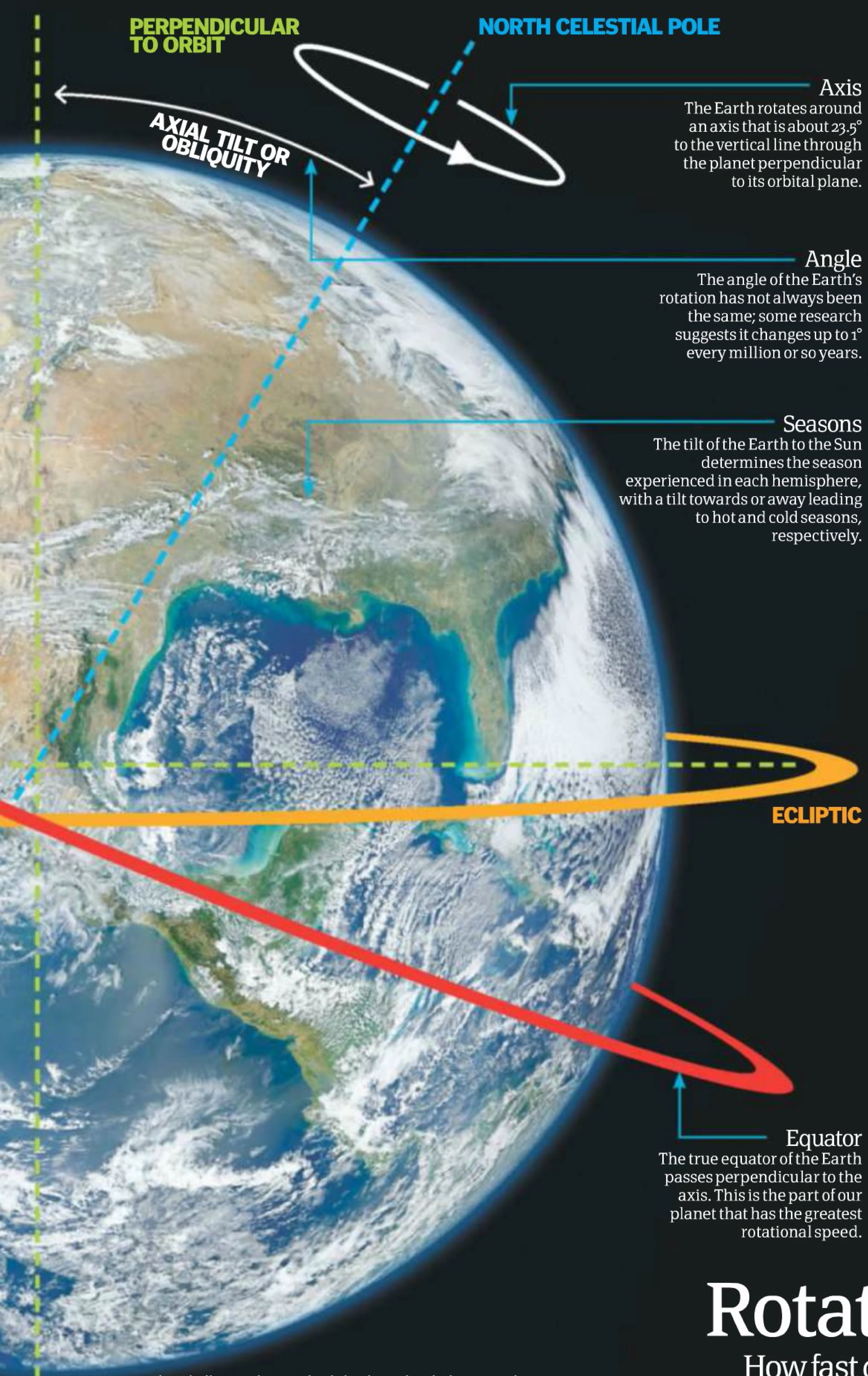
The culprit is the moon. It is our own natural satellite that has caused the planet to slow down, via something known as tidal locking. The moon, at the moment, is tidally locked to the Earth – that is, the same face always looks towards us, but it was not always so. When the moon first came into orbit around the Earth it was also spinning. To understand tidal locking, imagine that you and a friend both pull on a piece of rope, but at the same time you spin in a circle around a pivot at the centre of the rope. As you tug harder, you are eventually able to spin less and less fast. Eventually, you will be stuck simply pulling on the rope, unable to move sideways as your pulling force is too great; this is essentially what happened between Earth and the moon. As the moon orbits the world it exerts a pull on the planet, which is responsible for causing tides. The Earth is much bigger so it continues to spin freely, but the moon's rotation now matches the time it takes to complete one orbit. Small as it may be, the moon will continue to have an effect on Earth and, millions of years from now, a day on Earth could be up to 26 hours long.



Inertia
The law of inertia states an object will continue to move unless acted upon by another force, which is why Earth has not stopped spinning.

Ecliptic
The Earth orbits the Sun on a flat plane but it does not rotate perpendicular to this plane.

Poles
The poles experience little to no rotational force, and thus can experience prolonged daylight and darkness in summer and winter, respectively.



Axis
The Earth rotates around an axis that is about 23.5° to the vertical line through the planet perpendicular to its orbital plane.

Angle
The angle of the Earth's rotation has not always been the same; some research suggests it changes up to 1° every million or so years.

Seasons
The tilt of the Earth to the Sun determines the season experienced in each hemisphere, with a tilt towards or away leading to hot and cold seasons, respectively.

Equator
The true equator of the Earth passes perpendicular to the axis. This is the part of our planet that has the greatest rotational speed.

CG image of Earth showing its rotation compared to the rest of the solar system

© SPL

Getting in a spin

The rate of rotation of a body is determined by the rapidity of its formation (ie a faster collapse means a greater angular momentum is conserved). In our solar system, the distance to the Sun also determines how fast a planet will spin – the closer a planet is, the slower it will go and vice versa.

This is an effect known as tidal locking, which is demonstrated by moons that are tidally locked to their host planets. They begin spinning but eventually slow down and finally are gravitationally locked, so the same face always looks towards their host planet, much like our moon.

The fastest spinning objects in the universe are pulsars. These are neutron stars that are left behind after a giant star goes supernova. Pulsars have a huge amount of mass confined into a very small space, sometimes less than a few dozen kilometres across. For that reason they have a very high angular momentum; rotating up to 1,000 times/second.

> “The closer a planet is, the slower it will go and vice versa. This is an effect known as tidal locking”

Rotation comparison

How fast do other bodies in the solar system spin?

SUN	MERCURY	VENUS	EARTH	MARS	JUPITER	SATURN	URANUS	NEPTUNE
25.4 days	58.6 days	-243.01 days	0.997 days	1.03 days	0.41 days	0.43 days	-0.72 days	0.67 days

*A minus indicates the rotation is backwards relative to Earth

10 x © NASA

How was the Moon made?

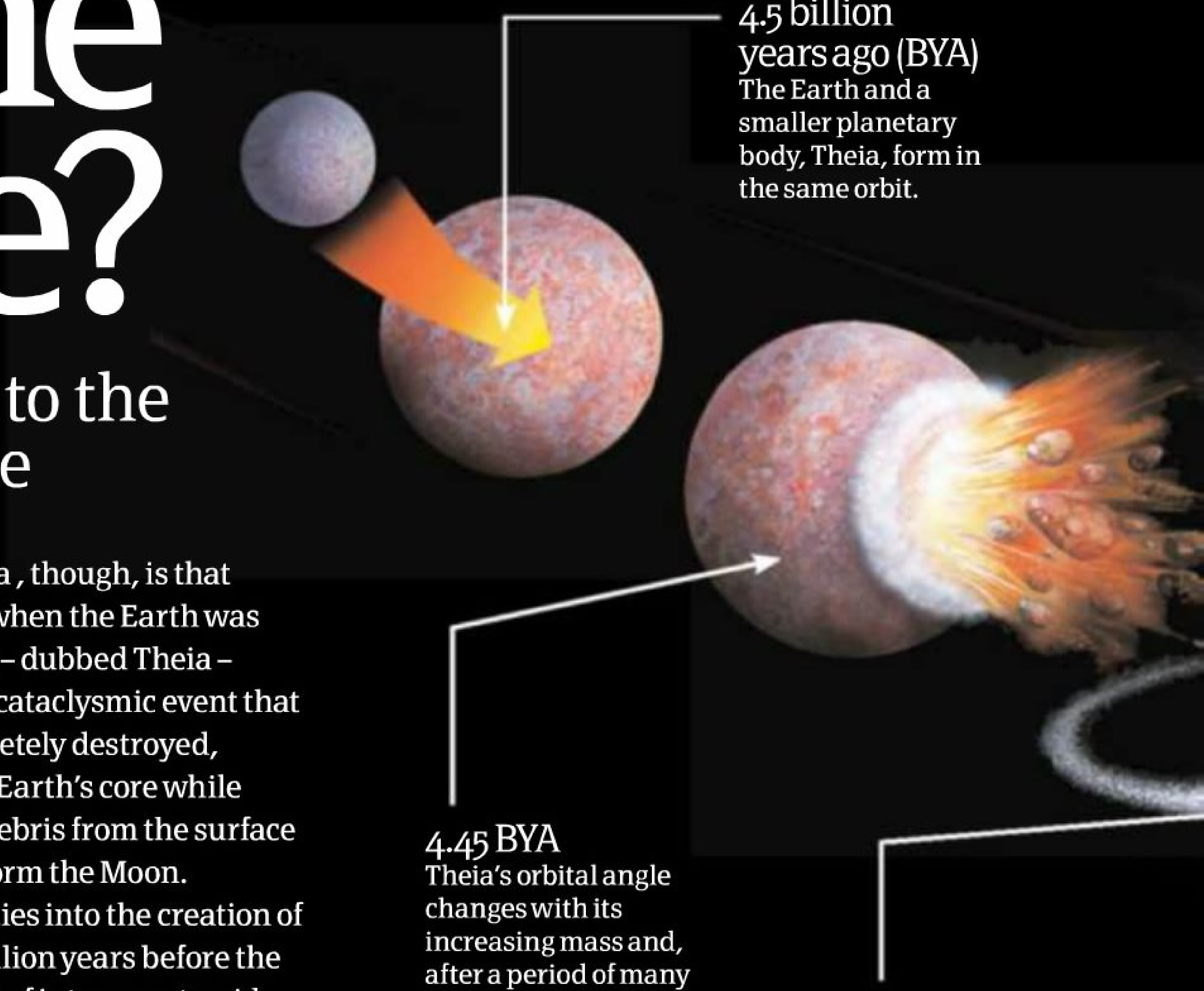
Discover the cataclysmic events that led to the formation of Earth's only natural satellite

Between 363,570 and 405,410 kilometres (around 220,000-250,000 miles) from Earth is our only natural satellite, the Moon. It's very different from its mother planet: it has around one-eighth of the Earth's mass, a very thin, almost negligible atmosphere and it's completely devoid of life. Yet it's very similar, with a distinct crust, mantle and solid iron core, plus a mineral composition almost identical to Earth's volcanic geology. A coincidence? Scientists think not.

There are four theories of the Moon's creation – three being discredited. One suggests the Moon is the result of dust coalescing during the formation of the Solar System; another that the Moon was an asteroid captured by Earth's gravity. `Fission theory' states that Earth was spinning so rapidly when it formed the molten mass split in two.

The generally accepted idea , though, is that around 4.5 billion years ago, when the Earth was forming, a Mars-sized planet – dubbed Theia – collided with it. It was such a cataclysmic event that the smaller planet was completely destroyed, sending its own iron into the Earth's core while throwing trillions of tons of debris from the surface into orbit. This coalesced to form the Moon.

This `giant impact' theory ties into the creation of our Solar System about 50 million years before the Earth formed during a period of intense asteroid bombardment that lasted for about 750 million years. This bombardment settled, either colliding with early planets (like Earth) being ejected from the Solar System or falling under the influence of the Sun's gravity and becoming part of the Asteroid Belt located between Mars and Jupiter. ❁



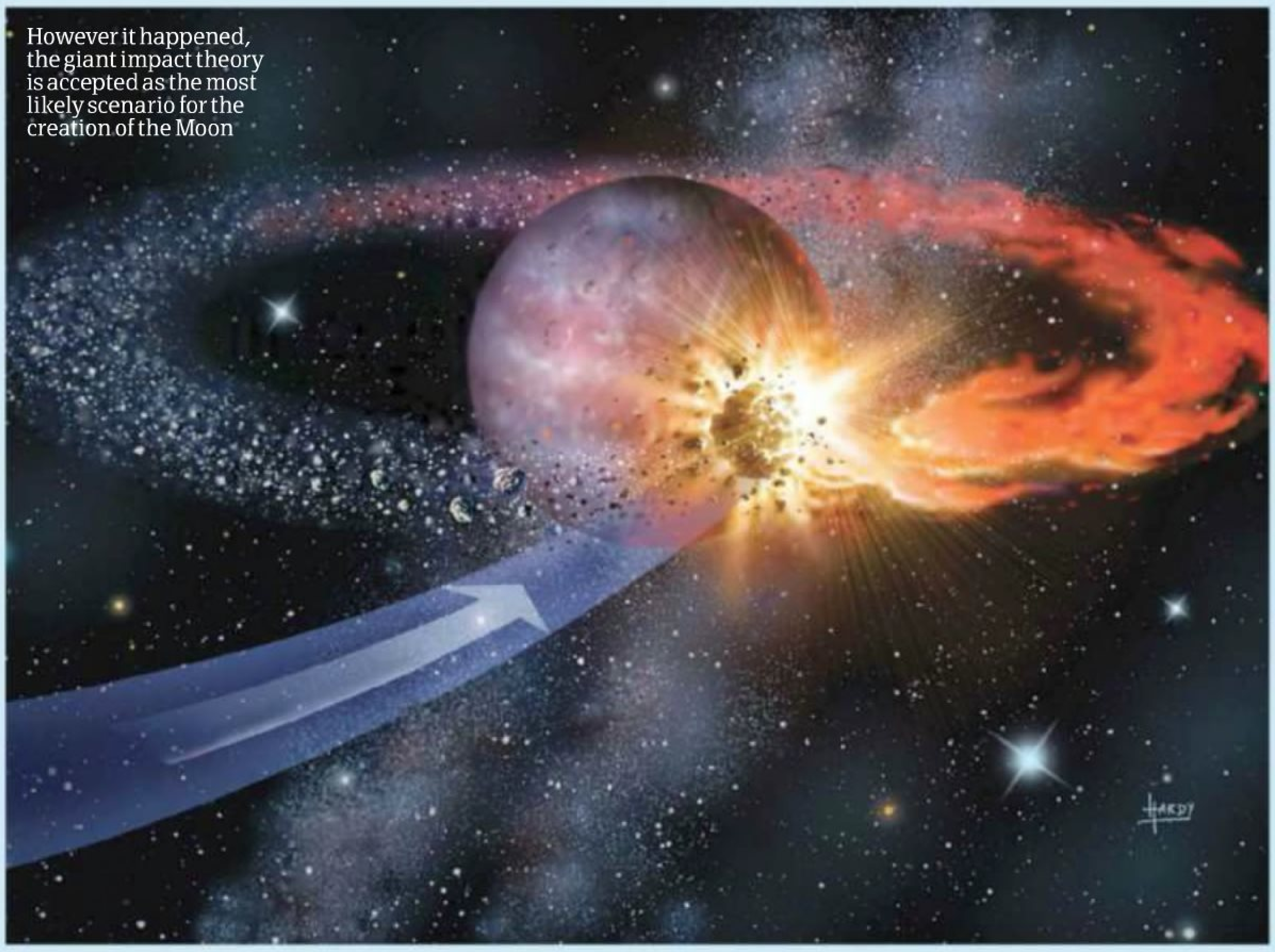
4.5 billion years ago (BYA)
The Earth and a smaller planetary body, Theia, form in the same orbit.

4.45 BYA
Theia's orbital angle changes with its increasing mass and, after a period of many years, it collides with the Earth.

4.43 BYA
Debris thrown out into orbit by Theia begins to coalesce under its own gravity to form the Moon.

Scientific doubts

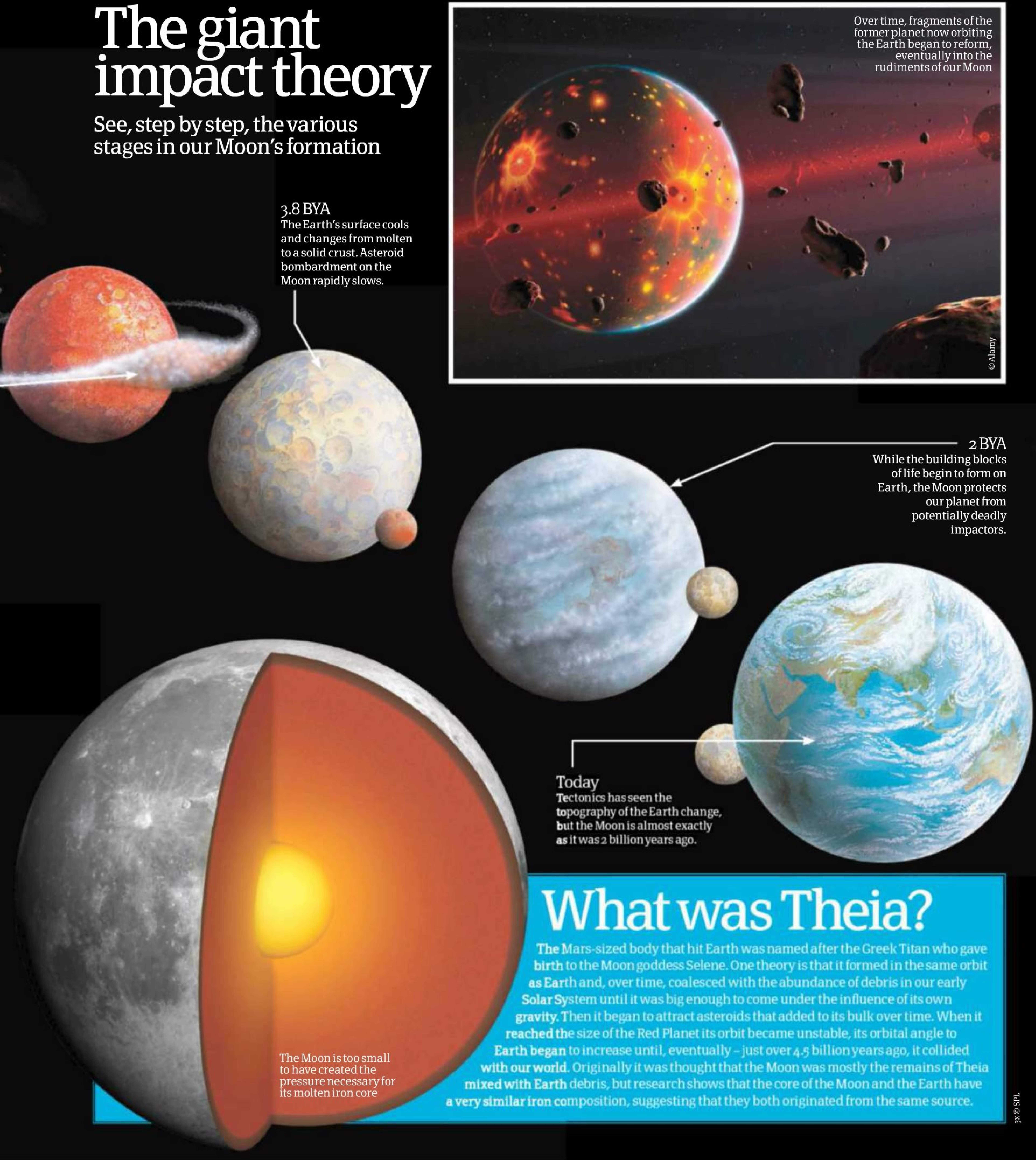
Recent studies of the Moon's chemistry by the University of Chicago revealed the surface is virtually identical to Earth's, which raised questions over the giant impact theory: if a Mars-sized planet struck our world, why is there no apparent trace of it? The impact is supposed to have been so colossal it nearly tore the Earth apart, causing it to warp into an oblong shape before rebounding under the force of its own gravity. Explanations include the possibility that Theia was a comet made of ice that could provide the required energy for the giant impact theory, but it subsequently evaporated. Scientists have also suggested that the Earth could have been spinning so fast at the time that Theia was thoroughly mixed into the Earth and the debris that eventually became the Moon. In either case, giant impact is still our most viable theory as to the creation of our lunar neighbour.



However it happened, the giant impact theory is accepted as the most likely scenario for the creation of the Moon

The giant impact theory

See, step by step, the various stages in our Moon's formation



Over time, fragments of the former planet now orbiting the Earth began to reform, eventually into the rudiments of our Moon

© Alamy

3.8 BYA
The Earth's surface cools and changes from molten to a solid crust. Asteroid bombardment on the Moon rapidly slows.

2 BYA
While the building blocks of life begin to form on Earth, the Moon protects our planet from potentially deadly impactors.

Today
Tectonics has seen the topography of the Earth change, but the Moon is almost exactly as it was 2 billion years ago.

The Moon is too small to have created the pressure necessary for its molten iron core

3x © SPL

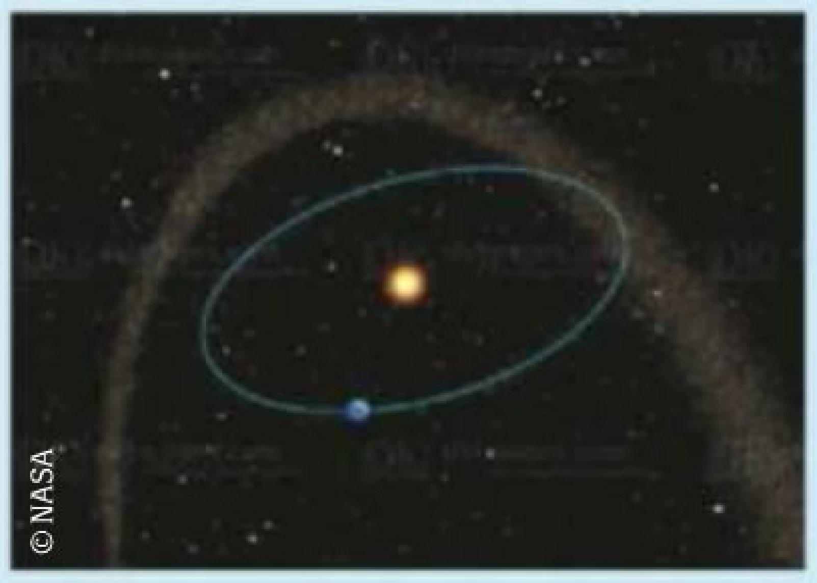
What was Theia?

The Mars-sized body that hit Earth was named after the Greek Titan who gave birth to the Moon goddess Selene. One theory is that it formed in the same orbit as Earth and, over time, coalesced with the abundance of debris in our early Solar System until it was big enough to come under the influence of its own gravity. Then it began to attract asteroids that added to its bulk over time. When it reached the size of the Red Planet its orbit became unstable, its orbital angle to Earth began to increase until, eventually – just over 4.5 billion years ago, it collided with our world. Originally it was thought that the Moon was mostly the remains of Theia mixed with Earth debris, but research shows that the core of the Moon and the Earth have a very similar iron composition, suggesting that they both originated from the same source.

© SPL

The Leonids

While not the most consistent of meteor showers, the Leonids can be one of the most dynamic spectacles in an astronomer's calendar. They're a product of the comet Tempel-Tuttle, which has a radius of around 1.8 kilometres (1.1 miles) and has a 33-year cycle. The comet itself is fairly unremarkable compared to the likes of Halley's or Hale-Bopp, however it leaves behind a dense stream of debris that results in a meteor shower rate that can reach as many as 300 meteors an hour.



© NASA

What causes meteor showers?

Why the most famous of these celestial spectacles are an annual event

Meteors enter the Earth's atmosphere all the time, without most of us even being aware of it. Spend a little time looking up at the sky at night in the country or a place with similarly low light pollution and there's a good chance you will see a 'shooting star', the result of air friction burning the meteor up. At certain times of the year astronomers can even forecast an increase in their frequency and luminosity as annual meteor showers hit our planet. So why do these occur regularly and how are scientists able to predict them?

A meteor shower is a group of meteors that originate from the same source. In the common case of one of the most prolific annual meteor shower events in the cosmic calendar, the Perseids, they're material stripped off the comet Swift-Tuttle by solar radiation as it passes the Sun. This debris then trails behind the comet, spreading out along its orbit and, if the Earth's own orbit crosses its path, then a meteor shower ensues. As it happens, both Earth and Swift-Tuttle follow very regular paths, which is why when Earth crosses Swift-Tuttle's orbit a predictable, late-July event occurs that peaks in August at around 75 meteors an hour.

Perhaps the most famous comet of them all, Halley's, has its own regular meteor shower called the Orionids that appear in October, though at a much lower rate than the Perseids. ✿

Is the Swift-Tuttle comet a threat?

Swift-Tuttle has a 130-year orbit of the Sun and its first recorded sighting was by astronomers Lewis Swift and Horace Tuttle 150 years ago in July 1862. Astrophysicist Brian Marsden's calculations for the next perihelion (the name for any satellite's closest approach to the Sun) in 1992 were off by 17 days, which put the comet on a potential collision course with Earth in 2126. It panicked astronomers, as the comet is around 9.7 kilometres (six miles) wide, which is roughly the same size as the Chicxulub asteroid that's generally held to be the major culprit in the extinction of the dinosaurs 65 million years ago. But having traced Swift-Tuttle's orbit back 2,000 years, Marsden was able to refine his calculations to put the comet a comfortable 24 million kilometres (15 million miles) away for its next appearance. However, if the calculations play out, there *will* be a real cosmic near-miss when 3044 rolls around, as Swift-Tuttle will pass within just 1.6 million kilometres (1 million miles) of our planet.

How would you evacuate the ISS?

If you ever venture to the ISS, make sure you have the Soyuz spacecraft on speed dial for a quick getaway!

In the event of an emergency, how is the International Space Station cleared?

In June 2011, the ISS came within a hair's breadth of disaster. Space debris orbiting the Earth at a fatal velocity was spotted too late to make a 'ducking' manoeuvre, so the six-man crew was relocated to the Soyuz spacecraft in case the station hull was punctured. As it turned out, the debris passed by within 250 metres (820 feet) and the crew was able to return safely to their work.

The International Space Station is partially autonomous and many of its essential systems can be controlled from the ground here on Earth. The main reason for having a crew on board is to fix any problems the ISS experiences that require a human presence to put right. In an emergency, evacuation would be a simple process of closing hatches between each module to isolate each room on the astronauts' way back to the Soyuz spacecraft, which would then carry them to safety back down on Earth.

© NASA

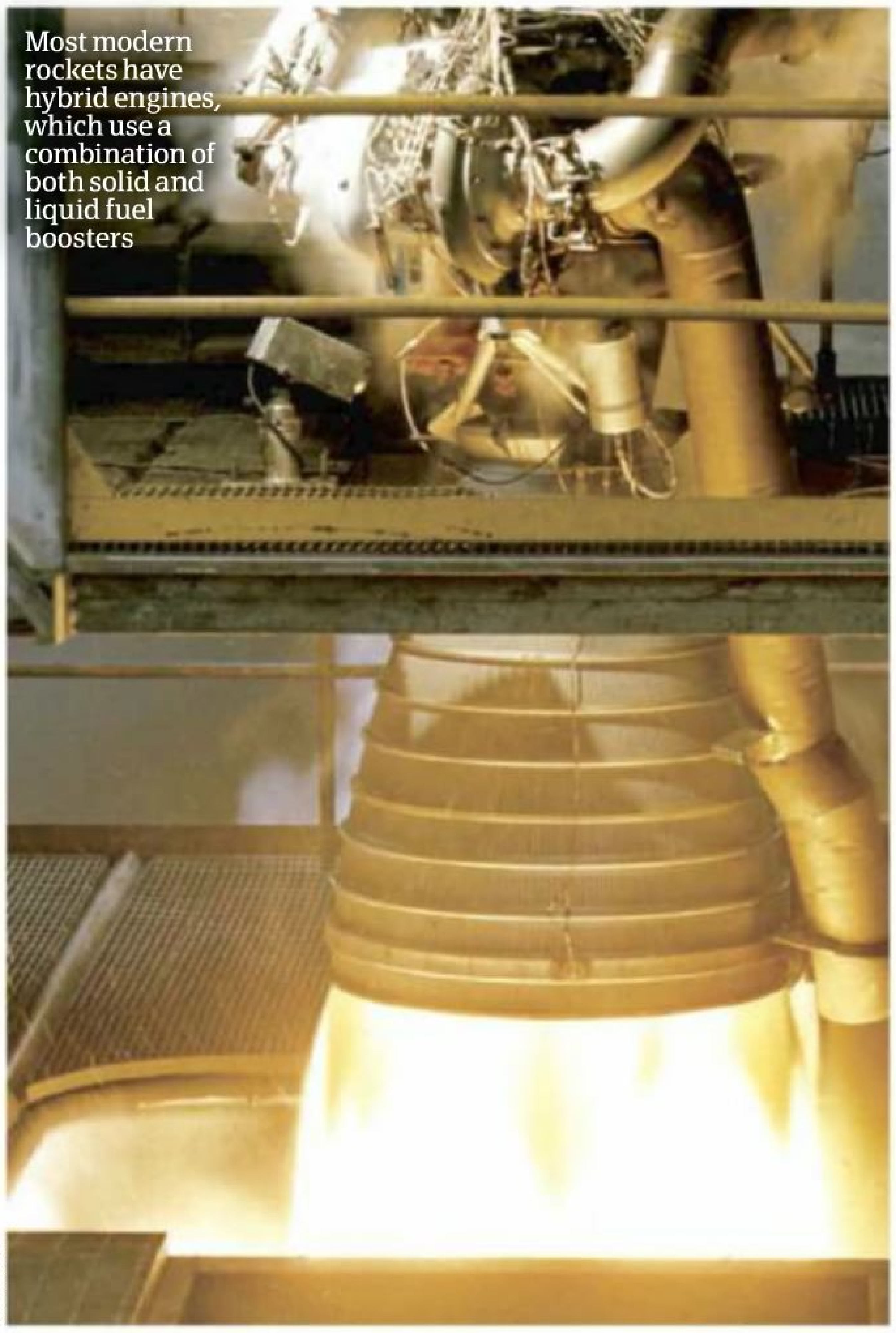
What is rocket fuel made of?

How does this powerful propellant take spacecraft into the cosmos?

Rocket fuel works on the basis of Newton's Third Law of Motion, which states that 'every action is accompanied by an equal and opposite reaction'. By firing fuel out the back of a rocket, the force propels it upwards with acceleration equal to the force at which the fuel is expelled. It's similar to how a jet plane is able to fly in the atmosphere. However, jet planes use oxygen in the atmosphere to ignite their fuel, while a rocket must carry its own oxidiser.

There are two main types of rocket fuel: liquid and solid. Liquid propellants separate fuel and oxidisers and the two are combined in a combustion chamber where they burn and are fired out from the base of the rocket. The ability to control the flow of propellant means the engine can be throttled to a particular speed. Liquid fuels are further subcategorised into either petroleum, cryogens or hypergols. Petroleum is fuel derived from crude oil and hydrocarbons, cryogens are those stored at very low temperatures, while hypergols are able to self-ignite on contact between the fuel and the oxidiser.

Solid rocket fuels are those in which the fuel and oxidiser compounds are already combined. Most use an aluminium powder as the fuel and an ammonium perchlorate as the oxidiser, while an iron powder is used as a catalyst for the reaction. All that's required is a spark to start them burning. While they are simpler than their liquid counterparts, they cannot be stopped once they have been ignited. For that reason, solid fuels are generally used for the launch sequence, when the speed needs to be at its maximum, whereas liquid fuels are used later so the speed can be adjusted to get the payload on to the right trajectory.



Most modern rockets have hybrid engines, which use a combination of both solid and liquid fuel boosters

© NASA

Why does Saturn have rings?

The mysteries of how Saturn's rings were formed are only now revealing themselves to us…

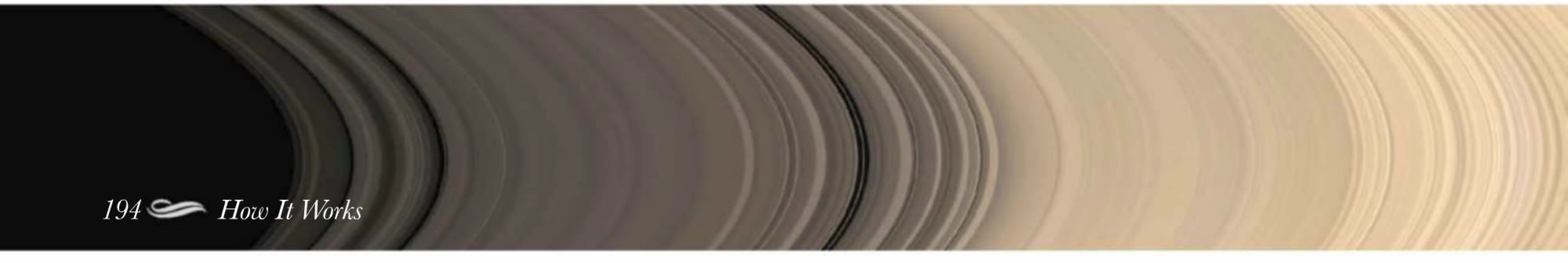
While both Neptune and Uranus can boast of being encircled by a stellar crown of sorts, it's Saturn that is the true 'lord of the rings'. Neptune's five relatively thin rings are so small that they weren't definitively discovered until 1968, while Uranus's narrow bands were discovered even later, in 1977. By contrast, Galileo was the first person to view Saturn's rings over 400 years ago using a simple telescope.

Six of its seven rings span from 74,500 kilometres (46,300 miles) to 140,220 kilometres (87,130 miles) above the surface of Saturn, while its diffuse E ring is truly gigantic at around 300,000 kilometres (186,000 miles) wide – nearly the distance between the Earth and the Moon.

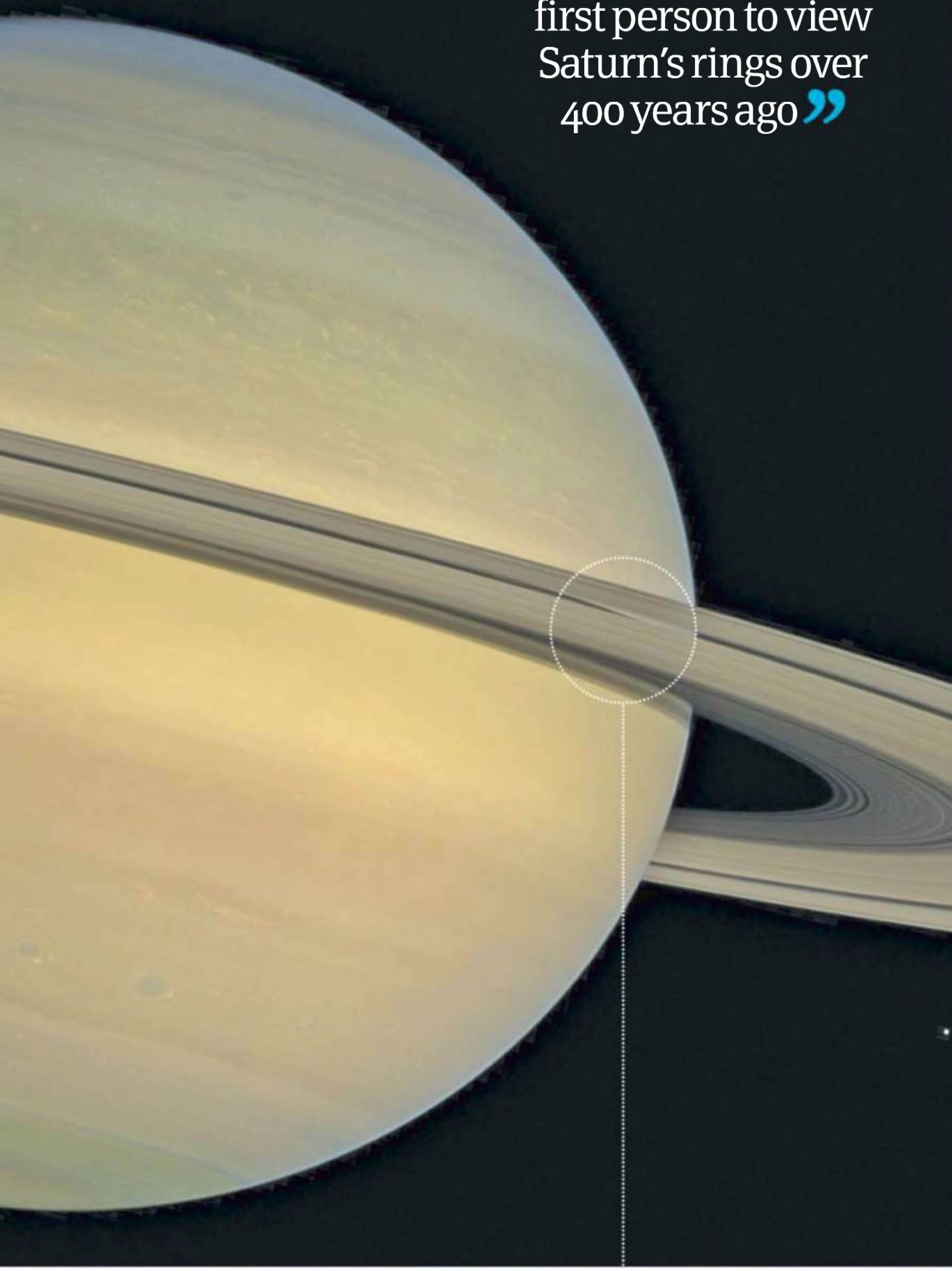
Most of the rings are primarily composed of water ice that ranges in size from tiny droplets micrometres across to large chunks the size of houses. Icy moons like Enceladus that orbit Saturn help seed the enormous E ring by spouting water slush and organic compounds from beneath its frozen crust into the atmosphere and way beyond. Rock particles of a similar size, but much greater mass than the ice particles, can also be found within the rings.

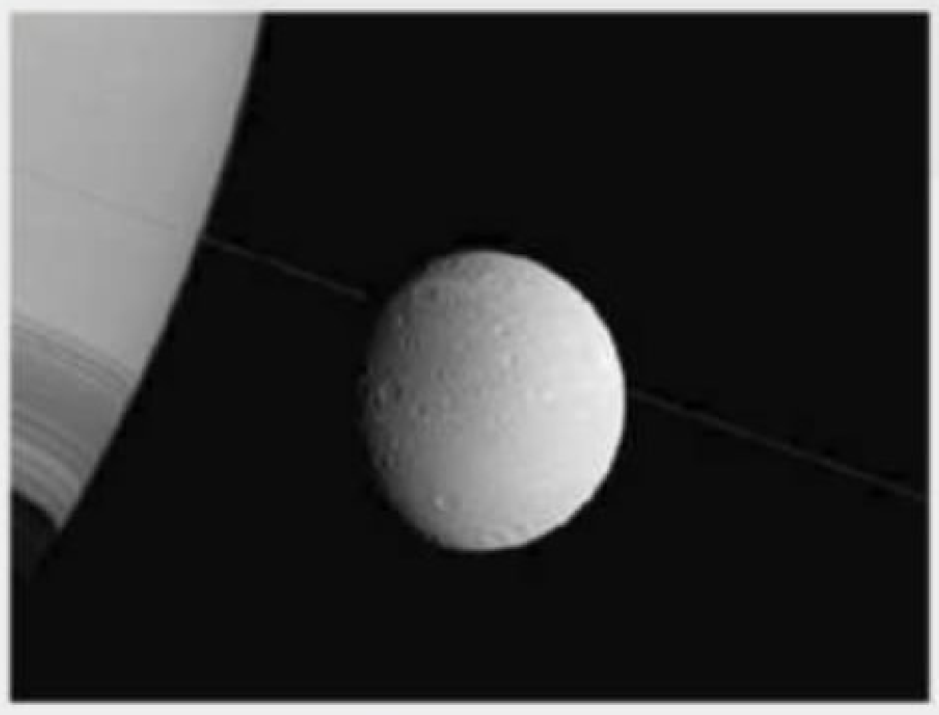
One theory is that Saturn's main rings, A, B and C – the first ones that were discovered – were actually created much later than had been previously thought. Rather than at the time of the formation of the Solar System, space scientists think the rings may have been formed a few hundred million years ago when a large moon or asteroid was broken apart by Saturn's gravity. ✺

Saturn's rings close up



> “Galileo was the first person to view Saturn’s rings over 400 years ago”





Moonlets

The Cassini-Huygens mission has thrown new light on the formation of Saturn’s moons. Some of the smallest moonlets that measure less than 50 kilometres (31 miles) across should have been destroyed by comets if they were captured by Saturn’s gravity at the formation of the Solar System, as per the old theory. Using data collected by the Cassini probe, a computer simulation suggests that the ice in the rings can piece together into large enough lumps to come under the influence of their own gravity, then continue to grow as Saturn pushes them out on a gravitational tide. It also helps explain why the biggest moons are farthest from the gas giant.

2x © NASA

How do airlocks work?

These chambers safely transit astronauts into the vacuum of space

Airlocks, typified by the International Space Station's (ISS) primary Quest Joint Airlock, are designed to permit safe passage of people and objects between a pressurised vessel and its surrounding environment. Further, they are designed to minimise pressure and air-level changes within the host craft.

The Quest airlock of the ISS is split into two main sections: an equipment chamber and crew lock chamber. The former connects to the ISS and supplies an auxiliary holding bay for any essential equipment, such as Extravehicular Mobility Units (EMUs – or spacesuits), as well as other key gear. It also supplies a staging area where astronauts can prepare for a spacewalk – namely get in and out of their spacesuits.

Connected to the equipment compartment is the crew lock, a smaller cylindrical chamber into which astronauts enter prior to any spacewalk. Once inside this section, the interior hatch between the equipment lock and the crew lock is shut. This provides a sealed environment for the suited astronaut and allows depressurisation to proceed. When the crew lock is fully depressurised, an external hatch becomes operational, providing an exit for the astronaut to enter space.

Importantly, before any spacewalk is attempted, astronauts must 'camp out' within the equipment chamber of the airlock in a reduced-nitrogen environment in order to purge nitrogen from their blood stream. This ensures that astronauts avoid decompression sickness in the low pressure experienced within the pure-oxygen atmosphere of the spacesuit. Nitrogen and oxygen are supplied and replenished via four externally mounted gas tanks, which ensures that the lock does not need to draw upon the host ISS's own gas supplies.

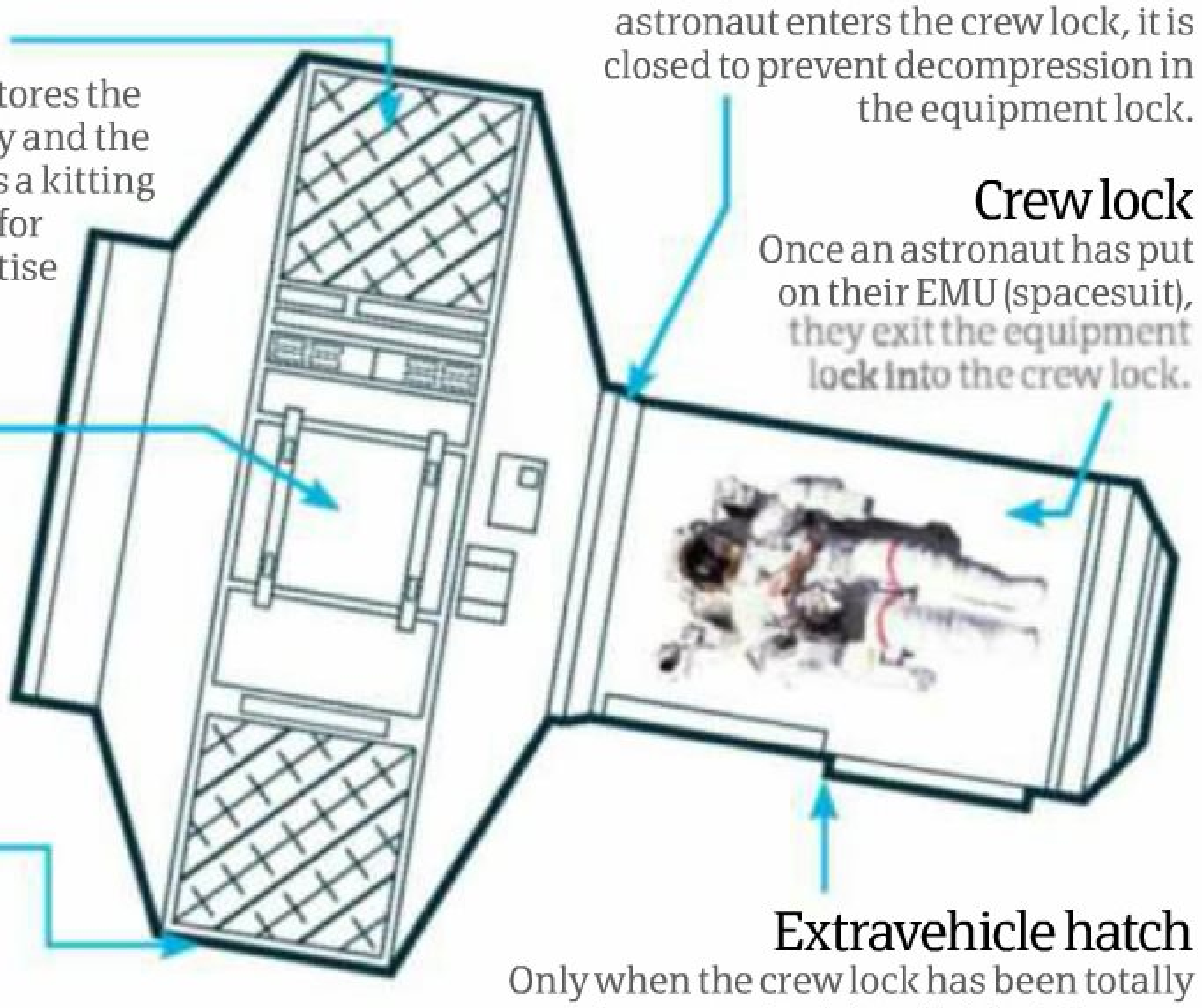
The Quest airlock module of the International Space Station being prepped prior to launch

3x © NASA

NASA astronaut Garrett Reisman inside the Quest Joint Airlock

Inside an airlock

Discover the key areas of the International Space Station's Quest airlock



Equipment lock
The equipment lock stores the airlock's power supply and the spacesuits. It provides a kitting up area and a chance for astronauts to acclimatise to the EMU.

Power supply
assembly The entire airlock is powered from a central power supply assembly located in the equipment lock.

Gas tanks
Nitrogen and oxygen tanks replenish gas lost during hatch opening for any spacewalk.

Intravehicle hatch
This provides a sealed barrier between the equipment and crew locks. As an astronaut enters the crew lock, it is closed to prevent decompression in the equipment lock.

Crew lock
Once an astronaut has put on their EMU (spacesuit), they exit the equipment lock into the crew lock.

Extravehicle hatch
Only when the crew lock has been totally depressurised does this hatch open, allowing the astronaut to venture into space.

* * *

What is a cleanroom?

Why do these rooms need to be so spotless?

A cleanroom is a secured environment where the level of particulate matter in the atmosphere is strictly controlled. All pollutants such as dust, chemical vapours and aerosols are monitored and eradicated by an internal conditioning system, which includes a combination of filters, extraction fans, airlocks, air showers and protective clothing for its workers.

Via this system, a controlled number of particles per cubic metre (and of a specific size) can be ensured, with higher-class facilities capable of delivering smaller and fewer particles. For instance, an ISO 1 cleanroom – the highest grade; there are nine in total – allows no more than two two-micrometre particles per cubic metre. For perspective, a typical urban environment has 35 million particles of all sizes per cubic metre.

Cleanrooms are used by NASA when building, testing and integrating spacecraft components to ensure no contamination or damage is done to the sensitive and expensive equipment – technology that once launched into space cannot be decontaminated. Indeed, while tiny specks of dirt may seem insignificant, past experiences and studies have shown that even the tiniest piece of pollen, sand, hair or flake of skin can imbalance a star-tracking unit, damage an exhaust port or even lead to a spacecraft's thruster becoming blocked.

As such, whenever a NASA engineer comes into work, they must first change into their protective clothing, pass through an air shower – essentially a human-sized hand-dryer that removes any particles stuck to the suit – proceed through a secure airlock equipped with extraction fans, and then pass through a temperature and humidity-controlled room to the assembly area. Only then, and under the constant filtering process of a laminar flow filtration system, can they begin work.

A team of engineers working on the SM4 mission to the Hubble Space Telescope in the High Bay Cleanroom (the world's largest)

Cleanroom engineers prepare a Science Instrument Control and Data Handling Unit

2x © NASA

An MMU enables astronauts to move untethered in space

Space mechanics

The pros and cons of anyone working in space is that you, as well as any other object, have no apparent weight. This can be great when you need to lift heavy objects around, like the 148-kilogram (326-pound) MMU, but only when you're secured to something with much greater mass than the object you're trying to shift. Newton's third law of motion states that for every action there must be an equal and opposite reaction, so the average 80-kilogram (176-pound) astronaut trying to manually push the MMU around, without standing on the Orbiter, will only succeed in pushing themselves away at a much greater velocity than they can move the MMU.

What is a space jetpack?

How NASA's MMU works as a jetpack in space

Space jetpacks exist, though they don't work quite as you'd see in the movies. So when, on 12 February 1984, the astronaut Bruce McCandless went free-flying 40 metres (131 feet) away from the Orbiter – farther than anyone had ever been from the safety of their ship – it was a considerable achievement. It was made possible using NASA's Manned Maneuvering Unit (MMU), a nitrogen jet-propelled backpack that is currently the most practical answer to science fiction's idea of a working jetpack.

Fully loaded with gaseous nitrogen propellant, the MMU weighs a hefty 148 kilograms (326 pounds). It comprises two aluminium tanks with Kevlar filament wrappings to protect them from punctures and improve strength. Each tank is loaded with 5.9 kilograms (13 pounds) of nitrogen under 20.7 kilopascals of pressure, which is enough propellant for six hours' worth of extra-vehicular activity (EVA).

Each tank feeds an individual system of thrusters through to a combination of 24 nozzles, three on each of the eight corners of the MMU. The astronaut uses their fingertips to manipulate the individual controllers, the right-hand controller rotating the MMU for roll, pitch and yaw, the left-hand controller pushing the MMU forward, back, up, down, left and right.

Once the astronaut has achieved their required position, they can subsequently engage an altitude hold function that maintains it, allowing them to work without constantly monitoring the MMU.

On one of the shuttle missions following McCandless's ground-breaking EVA flight in November 1984, astronauts Joseph Allen and Dale Gardner were able to use the revolutionary MMU to capture two rogue communication satellites which had faulty propulsion modules, then bring them back to the Orbiter to be returned to Earth.

SAFER jetpacks

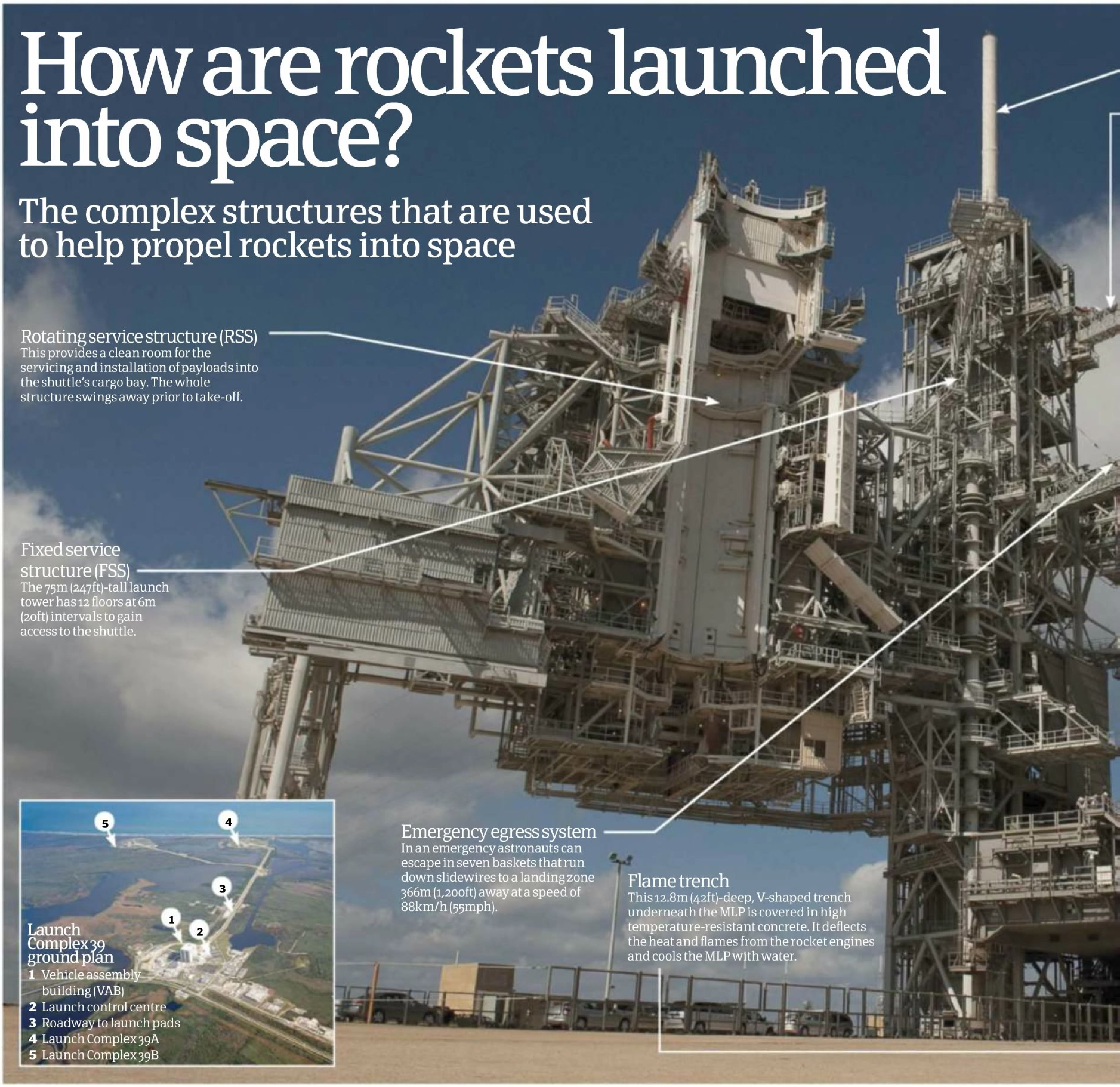
More recent developments in jetpack technology have resulted in SAFER, the Simplified Aid for EVA Rescue. This is a smaller unit than the MMU and works as a safety device for use on the International Space Station (ISS). In the event of an ISS crew member working on the structure drifting away without hope of retrieval, they can use this device to return to the station.

It fits over the life support system of a spacesuit (the EMU) and has a control module and display that moves from the bottom of the SAFER to the front during operation. It has a similar build to the MMU, with gaseous nitrogen expelled from 24 nozzles that can propel the user with a similar manoeuvrability. But because it only holds 1.4 kilograms (three pounds) of propellant, it can't manage the same velocity change as the MMU.

2x © NASA

How are rockets launched into space?

The complex structures that are used to help propel rockets into space



Rotating service structure (RSS)
This provides a clean room for the servicing and installation of payloads into the shuttle's cargo bay. The whole structure swings away prior to take-off.

Fixed service structure (FSS)
The 75m (247ft)-tall launch tower has 12 floors at 6m (20ft) intervals to gain access to the shuttle.

Emergency egress system
In an emergency astronauts can escape in seven baskets that run down slidewires to a landing zone 366m (1,200ft) away at a speed of 88km/h (55mph).

Flame trench
This 12.8m (42ft)-deep, V-shaped trench underneath the MLP is covered in high temperature-resistant concrete. It deflects the heat and flames from the rocket engines and cools the MLP with water.

Launch Complex 39 ground plan
1 Vehicle assembly building (VAB)
2 Launch control centre
3 Roadway to launch pads
4 Launch Complex 39A
5 Launch Complex 39B

The launch of a rocket into space is the culmination of years of planning, work and expense, and the most important element in this process is the launch pad and its attendant facilities. The launch pad cradles, fuels and powers the rocket, before it is unleashed into the sky.

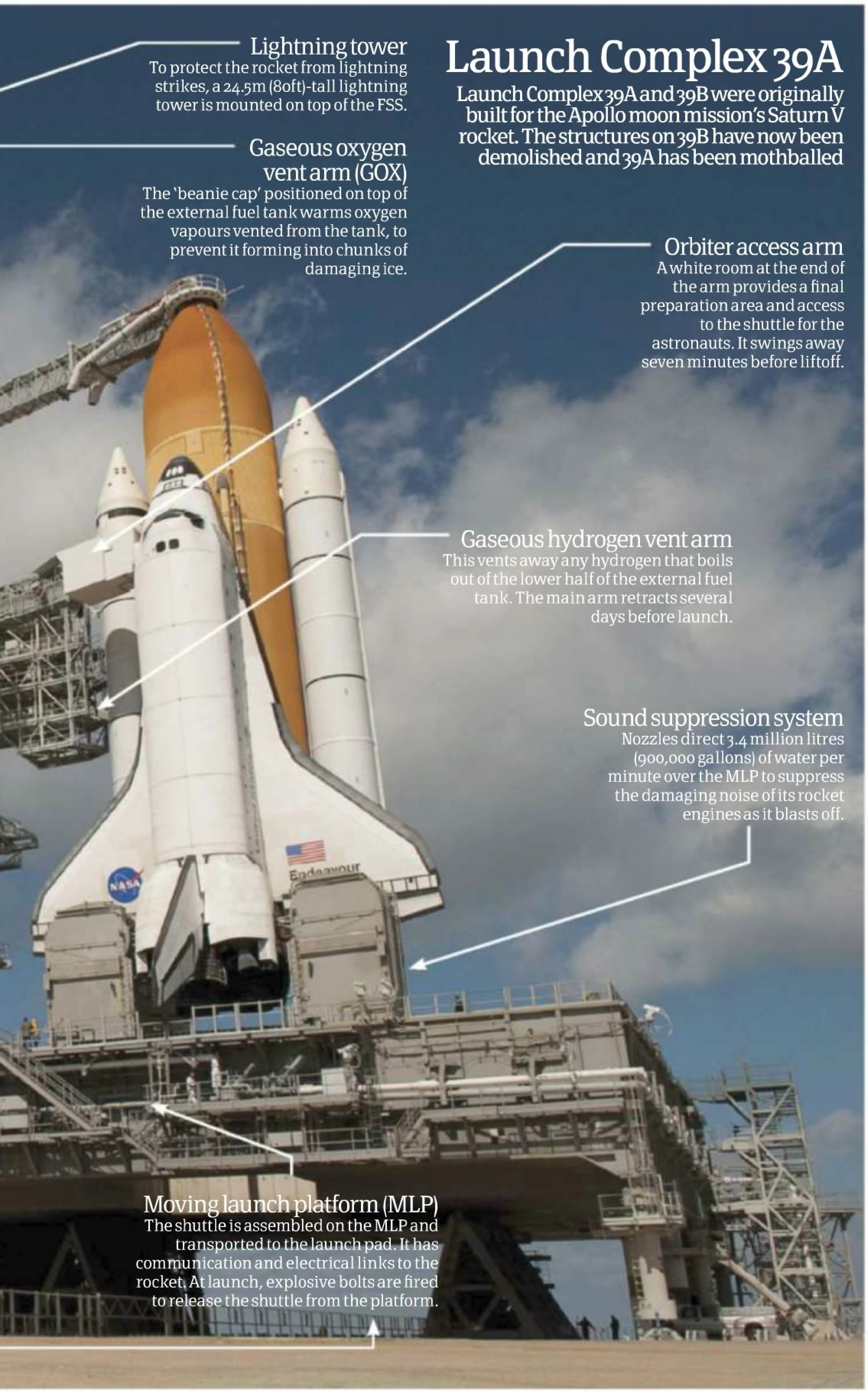
In the case of NASA's Space Shuttle, its rocket motors produced 3.2 million kilograms (7 million pounds) of thrust at launch. The corrosive exhaust and intense flames from the engines were channelled through a horizontal V-shaped flame trench, which consisted of two 453,600-kilogram (1 million-pound) deflectors made from steel coated with 12.7 centimetres (five inches) of heat-resistant Fondu Fyre concrete, which is sprayed with water and flakes off to disperse the intense heat.

The Space Shuttle was assembled on a moving launch platform (MLP) at the nearby vehicle assembly building (VAB) and taken to the launch pad on top of a crawler transporter. At the pad, a fixed service structure (FSS) has a lift to gain access to any level of the rocket. Anchored to it is the rotating service structure (RSS) that comprises a clean room used to load the rocket's cargo.

It took at least a month for 170 technicians and specialists, nicknamed 'pad rats', to prepare, check and launch the Space Shuttle, though for less complex, unmanned rockets the timescale is a matter of days. During the countdown, all links between the FSS and the rocket were systematically released, and lastly at blast-off explosive bolts free the shuttle from the MLP.

To protect the delicate components of the vehicle and the pad itself, the MLP is flooded with water at a rate of 3.4 million litres (900,000 gallons) per minute to suppress the damaging sound waves and heat produced by the engines.

Some support structures hold and guide the rocket, while others – like those at the Baikonur Cosmodrome in Kazakhstan – swing away from the rocket at the time of launch.



Launch Complex 39A

Launch Complex 39A and 39B were originally built for the Apollo moon mission's Saturn V rocket. The structures on 39B have now been demolished and 39A has been mothballed

Lightning tower
To protect the rocket from lightning strikes, a 24.5m (80ft)-tall lightning tower is mounted on top of the FSS.

Gaseous oxygen vent arm (GOX)
The 'beanie cap' positioned on top of the external fuel tank warms oxygen vapours vented from the tank, to prevent it forming into chunks of damaging ice.

Orbiter access arm
A white room at the end of the arm provides a final preparation area and access to the shuttle for the astronauts. It swings away seven minutes before liftoff.

Gaseous hydrogen vent arm
This vents away any hydrogen that boils out of the lower half of the external fuel tank. The main arm retracts several days before launch.

Sound suppression system
Nozzles direct 3.4 million litres (900,000 gallons) of water per minute over the MLP to suppress the damaging noise of its rocket engines as it blasts off.

Moving launch platform (MLP)
The shuttle is assembled on the MLP and transported to the launch pad. It has communication and electrical links to the rocket. At launch, explosive bolts are fired to release the shuttle from the platform.

2 x © NASA

Launch pad types

1 Mobile
The German V-2 WWII rocket was carried horizontally to any available launch site on a Meillerwagen trailer. At the site, a hydraulic ram on the wagon pushed the V-2 and its support gantry into a vertical position. It was then fuelled with alcohol and liquid oxygen by tanker trucks and fired from an armoured car.

2 Sea platform
Sea Launch AG has a base in Long Beach, CA, where it assembles the rocket payload and then loads it on the Sea Launch Commander ship where it is married with the rocket. The ship transfers the rocket to the converted drilling rig Odyssey Launch Platform, which is located in the Pacific Ocean on the equator. The launch is then controlled from the Sea Launch Commander.

3 Crawler transport
At the Kennedy Space Center, FL, rockets were constructed vertically in the vehicle assembly building (VAB) and taken by road on top of a specially built crawler transporter. The 40m (131ft)-long, 35m (114ft)-wide vehicle weighs 2.7 tons and, when fully loaded, has a maximum speed of just 1.6km/h (1mph).

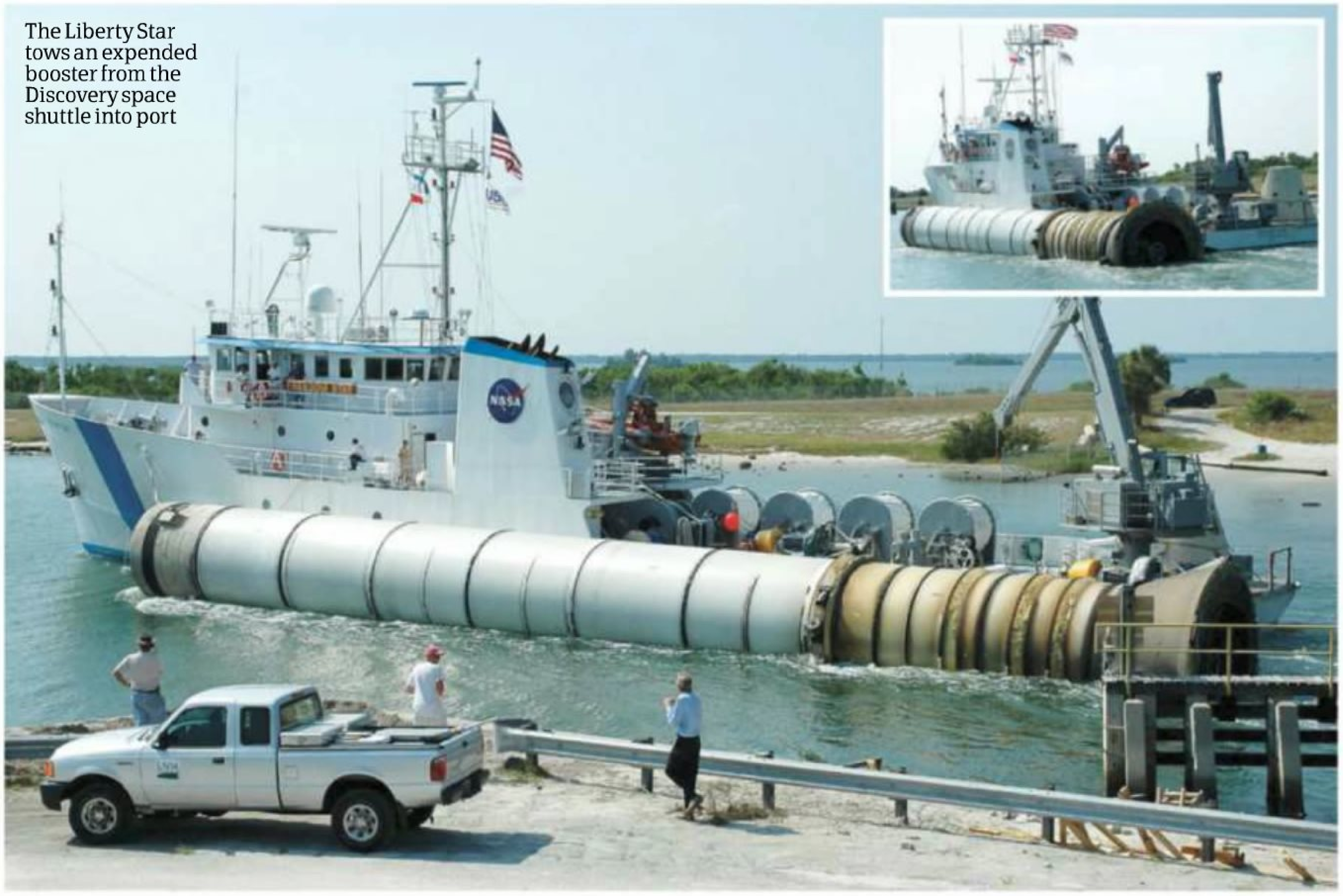
4 Railway
The Baikonur Cosmodrome, Kazakhstan, mainly uses a 470km (290mi), wide-gauge railroad network to transport its rockets to the launch site. The rockets are assembled and transported horizontally, and are erected to the vertical position at the launch pad.

5 Ramps
The WWII V-1 flying bomb used a catapult to fire it along a short 'ski' ramp to get it in the air. Using a rail or maglev track on a mountain slope, aided by a jet or rocket booster, larger payloads could be launched with great cost and fuel savings. Today, similar systems are still being tested.

Launch emergencies

Rocket fuel is highly volatile, and when a rocket is fully fuelled and ready for launch it is like a bomb ready to explode at any moment. Problems are caused when the complex sequence of launch procedures are not followed properly, or if one or more system failures cause the rocket propellant to leak or ignite prematurely. As a rocket lifts off any loose debris or acoustic shock can severely damage the rocket and very quickly lead to a catastrophic accident.

> “It took 170 specialists, known as 'pad rats', to prepare, check and launch the Shuttle”



The Liberty Star tows an expended booster from the Discovery space shuttle into port

Space ships

The Liberty Star and Freedom Star are designed by NASA specifically for the task of recovering boosters. They were built in a dry dock near Jacksonville, FL, in 1980 and 1981, are nearly 54 metres (180 feet) in length and displace over 1,000 tons of water. Twin engines provide 2,163 kilowatts (2,900 horsepower) to the propellers, but, curiously, also to two thrusters, one of which is a 317-kilowatt (425-horsepower) water jet thruster designed to protect manatees indigenous to the river where the ships are based. The vessels are crewed by ten mariners, nine SRB retrieval experts plus a supervisor, one NASA representative and several independent observers.

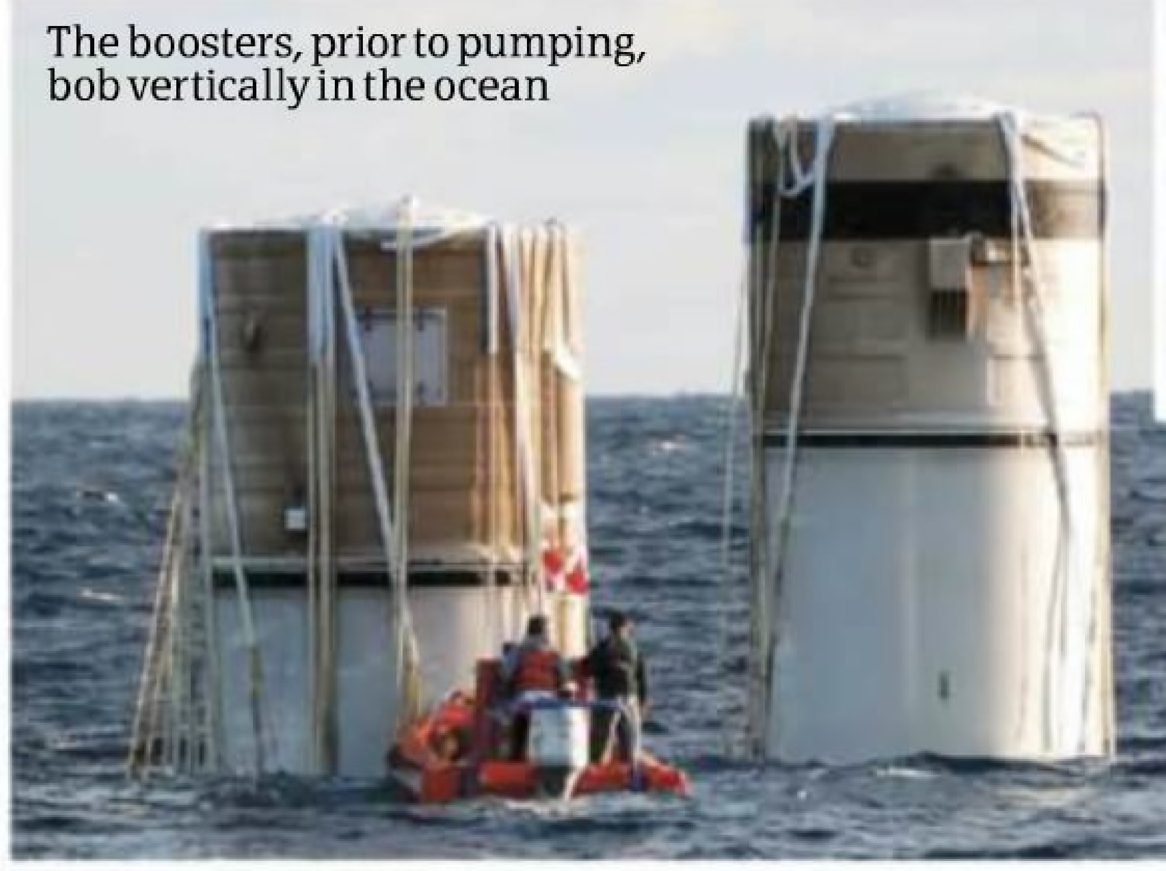
How are rocket boosters recovered?

Dropped from the edge of the atmosphere, here's how NASA salvages its solid rocket boosters

Solid rocket boosters (SRBs) are very expensive pieces of kit. In fact, they cost NASA around $25 (£15.7) million to manufacture from scratch, so a cost-efficient recovery and refurbishment system was implemented in the Eighties that's still used today.

Most shuttle flights follow a predictable path across the Atlantic Ocean as they ascend into space. So, once the SRBs have expended 500,000 kilograms (1.1 million pounds) of solid rocket fuel, they separate from the rocket and begin their 72-kilometre (45-mile), parachute-assisted descent back down to Earth. Seven minutes after liftoff the SRBs will splash down into the ocean, around 260 kilometres (160 miles) from the launch pad and float helplessly in the water. That's when NASA's SRB recovery ships are deployed.

The Liberty Star and Freedom Star can recover one SRB each. Nearly everything can be salvaged from these boosters and both vessels have specialist tools for the job. The four parachutes are first detached and wound on to a reel, before the crew can focus on the SRB itself. Then a diver-operated plug (DOP) is deployed and installed into the nozzle to help remove the water inside the booster. Air is then pumped from the ship, through the DOP and into the SRB, displacing the water. As more seawater is pushed out of the booster casing, it rises vertically until it topples onto its side, at which point it's ready to be towed back home to Cape Canaveral, FL, for dismantling.



The boosters, prior to pumping, bob vertically in the ocean

When successfully pumped of water, the booster floats horizontally, ready for delivery and dismantling

5x © NASA

SRB refurbishing

Having been retrieved from the ocean and returned to NASA, the SRBs are dismantled and inspected for damage before being refurbished for reuse on another shuttle flight.

Each SRB comprises a solid rocket motor, plus thrust vector control, structural, separation, recovery, electrical and instrumentation subsystems. The motor itself is loaded with solid propellant alongside its ignition hardware, which is mixed in three 2,730-litre (600-gallon) bowls and cast in special buildings, before being transported to its East Coast destination.

NASA's RS-88 concept engine, seen here, uses 22,680kg (50,000lb) of thrust to carry the crew out of harm's way

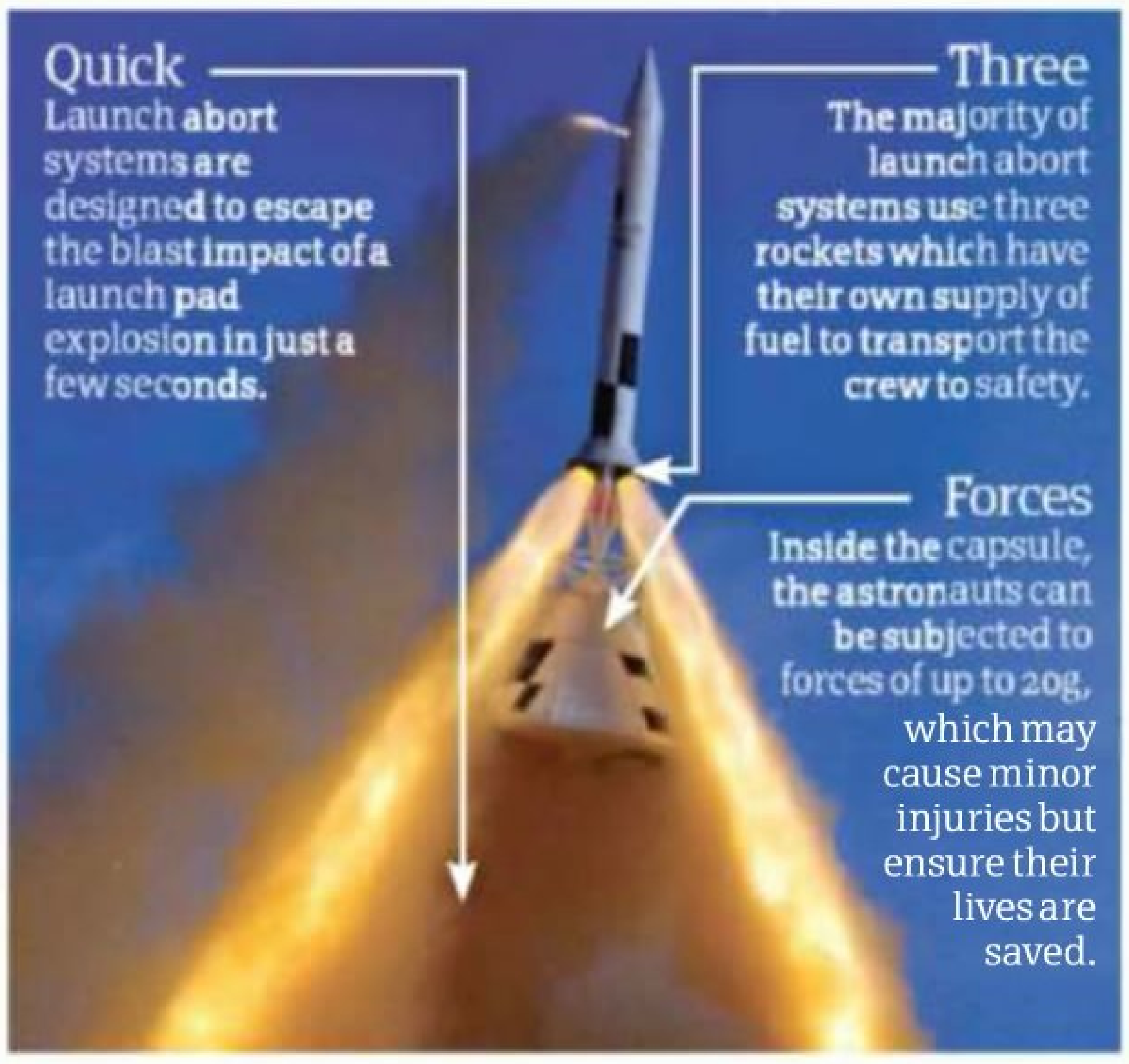
How are launches aborted?

How do astronauts escape in an emergency?

A launch abort system is a top-mounted rocket designed to propel a crew to safety in case of a launch pad emergency. Usually, three retro-fitted rockets are employed to accelerate the crew capsule at forces up to 20g away from the launch pad, saving the lives of the astronauts. After firing the rockets, three parachutes deploy to bring the capsule safely to the ground. If the launch passes without a hitch then the launch abort system is jettisoned in orbit, where it burns up in the atmosphere.

The only documented use of a launch abort system not due to a malfunction was on 26 September 1983, when the Russian Soyuz-T-10-1 was counting down to take two crew members to the Salyut 7 space station. During countdown the rocket caught fire and the launch abort system sprung into action, carrying the cosmonauts to safety just two seconds before the rocket exploded.

While all launch abort systems to date have used a vertically mounted rocket on top of the manned capsule, US-based company SpaceX is developing a new type of system that will use side-mounted, retro-firing rockets to take its planned Dragon capsule to safety. These rockets will be used by the engineering firm's Dragon capsule during its mission if they are not used at launch, saving precious fuel and making the exercise as a whole far more cost-effective.



Quick
Launch abort systems are designed to escape the blast impact of a launch pad explosion in just a few seconds.

Three
The majority of launch abort systems use three rockets which have their own supply of fuel to transport the crew to safety.

Forces
Inside the capsule, the astronauts can be subjected to forces of up to 20g, which may cause minor injuries but ensure their lives are saved.

What happens in an emergency? How these systems save lives

1. Launch abort

If the rocket malfunctions, the LAS accelerates the capsule from the launch pad.

2. Distance

The crew capsule is carried several miles from the launch pad to avoid a potential explosion.

3. Parachutes

Once at a safe distance the capsule deploys its parachutes to bring the astronauts safely down to Earth.

What goes on in the Hypervelocity Gun Lab?

Why is NASA shooting objects at thousands of miles per hour in its New Mexico facility?

In 1996, a briefcase-sized piece of debris from the French rocket Ariane I collided with the military reconnaissance satellite Cerise in Earth's orbit. It was travelling at nearly 50,000 kilometres (31,000 miles) per hour – fast enough to vaporise part of Cerise's stabilisation boom and send the satellite spiralling into an erratic trajectory. Fortunately, ground control was able to set Cerise back on track so it could continue its mission. However, this could have been disastrous for a manned craft or space station like the ISS, which had its own near-miss with a fragment of the Russian satellite Cosmos 2251 that was travelling at 26,000 kilometres (16,155 miles) per hour, earlier in 2012.

NASA is well aware of the dangers of space junk that our half-century of spaceflight has left in orbit. The Space Surveillance Network in Colorado Springs, USA, monitors thousands of orbital objects travelling at an average of 33,000 kilometres (21,000 miles) per hour. Large chunks can be avoided, so the biggest threat to any mission is from the smaller pieces of debris – those between two and ten centimetres (one to four inches) in diameter that zoom around the Earth like super-accelerated bullets. These number in the tens of thousands in space but they are too small to track by even the most sophisticated surveillance systems on Earth.

For every kilogram of shielding placed on a shuttle, it costs NASA thousands of extra dollars, so the precise amount required for any mission is calculated at the White Sands Test Facility in New Mexico. This cutting-edge shooting gallery is home to four enormous guns with 36-metre (118-foot) barrels that can propel aluminium ball bearings at similar speeds to those which can be reached in space. NASA engineers will fire many of these at shuttle casings until they find one whose armoured outer layers prevent the pressure wall from being punctured. This ensures their costly missions are not disrupted by small - but very impactful - pieces of space junk.

> “NASA engineers will fire many ball bearings at shuttle casings until they find one whose armoured outer layers prevent the pressure wall from being punctured”

© NASA

Does every planet orbit around a star?

Lately, astronomers have begun discovering homeless exoplanets; that is planets that do not orbit a star and are simply wandering through space. Indeed, the galaxy may be overflowing with orphan planets according to recently published research. Using telescopes directed to the Galactic bulge, scientists discovered a bunch of Jupiter-mass planets through a technique called gravitational microlensing. There are estimates that star-less wandering planets could number in the billions and be equal in number to planets orbiting their host stars. Scientific presumption is that they may have been ejected from evolving planetary systems.

What powers space probes?

There are two ways with which you can power a space probe – solar power and nuclear power. The limit with solar power is that as you get further from the Sun, you receive less sunlight and so your power drops, which puts a limit on the distances these probes can travel. With nuclear power, the radioactive decay of radioactive material releases heat energy which they can use to generate power.

Is Earth's rotation starting to slow down?

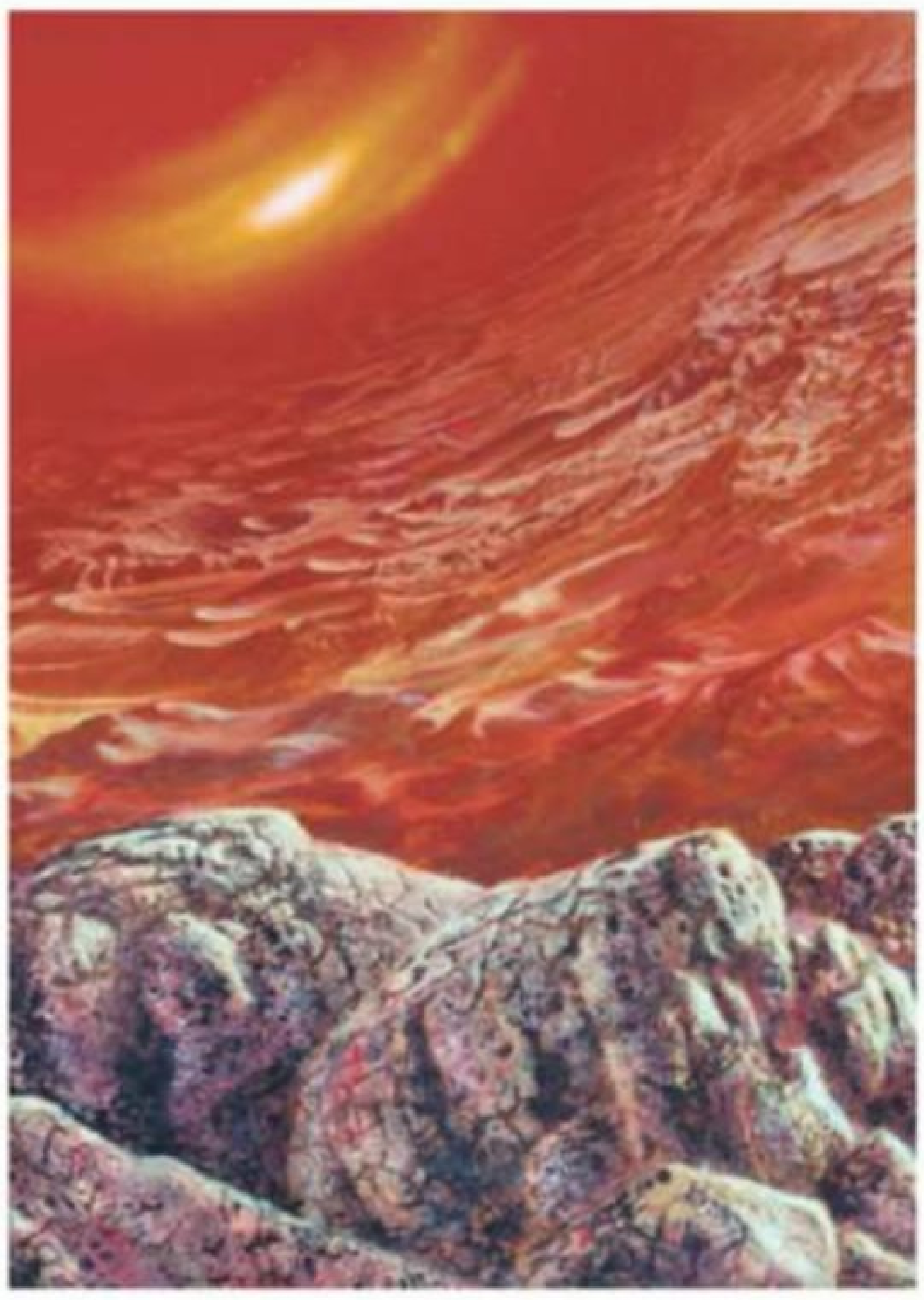
Yes, the Earth's rotation is slowing down due to the pull of the Moon's gravity on the Earth's oceans, which causes ocean tides. The tidal friction that results from the rise and fall of the oceans gradually transfers energy and angular momentum from the Earth to the Moon. The Earth's rotation is slowing at about 2.3 milliseconds per century due to tidal friction.

As the Moon gains energy and speed its orbit recedes from the Earth. The distance from the Earth to the Moon is increasing at about 39mm (1.5in) per year. Other factors such as global climate change and movement of the Earth's crust also cause a variation in the rotation rate.

Why do planets have magnetic fields?

Planetary magnetic fields are produced by churning motions of liquids at a planet's core that conduct electricity and have an electric charge. The magnetic fields act like giant bar magnets and can be offset from the rotation axis of a planet. For example, the Earth's magnetic field is tilted about 11 degrees to the axis of rotation. Magnetic fields protect a planet from the charged particles streaming out from the Sun in the form of the solar wind. The particles are deflected outwards by the magnetic field lines. Earth has a strong magnetic field because it has a liquid conducting core composed of iron-nickel that rotates swiftly every 24 hours. Mars exhibits a weak magnetic field because its iron core has cooled and perhaps solidified.

> “Magnetic fields protect a planet from the charged particles of the Sun”



Does it rain on other planets?

Yes, indeed there is 'rainfall' on other planets and moons, too, but it's far different from here on Earth. Highly corrosive sulphuric acid rains down from the thick clouds engulfing hellishly hot Venus. Liquid methane and ethane rain showers occur in the thick nitrogen atmosphere of Saturn's frigid moon, Titan. Geysers of water ice erupt from the south pole of Saturn's moon Enceladus (which has no atmosphere) and fall back to the surface as 'icy rain' due to the pull of gravity.

Why is the Moon visible during the day?

The Moon is visible in daylight every day, except when obscured from view by clouds, because its reflected light easily penetrates Earth's atmosphere. There are two exceptions; during new moon, when it's too close to our Sun, and during full moon when it's on the opposite side of the Sun and only rises above the horizon after sunset.

What is the interstellar medium?

All the matter floating in space between star systems in a galaxy, like the Milky Way, constitutes the interstellar medium. It is composed of gas, dust, magnetic fields and cosmic rays. Matter is in the form of ionic, atomic and molecular phases. But the density is very low and constitutes a near-perfect vacuum better than any produced artificially. 99 per cent of the interstellar medium is gas; of which about 90 per cent are atoms of hydrogen and nine per cent is helium – the most abundant elements in the universe. Dust comprises about one per cent of the medium. Altogether, the gas and dust in the interstellar medium amounts to about 15 per cent of the visible matter in our galaxy.

> "The gas and dust in the interstellar medium amounts to about 15 per cent of the visible matter in our galaxy"

What is the heliosphere?

The heliosphere is the immense magnetic bubble of charged, energetic particles which emanate from the Sun and surrounds our entire Solar System. They are blown outwards by the solar wind.

Beyond the heliosphere lies interstellar space – which is dominated by winds of hydrogen and helium gas. Some time in the next year or two, scientists expect that Voyager 1 will become humanity's first emissary to reach interstellar space and become the first man-made object to crossover from the heliosphere and depart our Solar System forever.

What makes meteorites so valuable?

Different factors affect the value of a meteorite, including origin, composition, condition and of course historical context. But the overriding factor that governs the value is the origin. Most meteorites are formed from the material left over from the formation of the Solar System. Prices for these can vary from about 50p per gram up to £40 per gram.

Lunar meteorites allow scientists to study the composition of our natural satellite and Martian meteorites are currently our only way to analyse Mars rock. These meteorites can sell for over £1,000 per gram!

Why do stars appear to twinkle in the night sky?

The twinkling of stars in our night sky is because of the Earth's atmosphere. As light travels from the stars towards the Earth it can easily move in a straight line. But once it enters and starts travelling through the Earth's atmosphere it gets bounced around in different directions by the particles of air.

For astronomers, this twinkling can be a huge problem, especially when they're trying to accurately image a particular star. The more the star twinkles, the blurrier the image will be.

If telescopes are launched into space, then all images can be taken without Earth's atmosphere in the way, but this is expensive. It is possible to use a system called 'adaptive optics', where tiny motors alter the surface of the telescope's mirror to correct for this blur caused by the air.

How are spacecraft tested?

Spacecraft are extensively tested before they are launched in order to ensure they can survive the harsh rigours of space. They are placed in a highly restricted and quarantined room and then baked and shaken, placed in a high vacuum chamber and bombarded with a high volume of sounds to test whether all of the mechanical and electrical components can withstand being in space and still function to carry out the mission for which they were designed. Every component is tested and retested – during all phases of spacecraft construction from early design to final assembly. For spacecraft journeying anywhere near potential habitats of life there are also additional stringent planetary protection protocols.

How old is the Sun?

The Sun was formed just over 4.5 billion years ago and is about halfway through its 10 billion year lifetime. In about 5 billion years the Sun's outer atmosphere will expand to a red giant and likely incinerate and swallow up the Earth. Since the Sun is also becoming more luminous and its surface temperatures are rising, the Earth's oceans will likely boil away and kill all life on Earth in a billion years or less.

How many people have been to outer space?

Before we can count how many people have been into space, we need to decide where space begins. This isn't something that everyone agrees on. The world body for aeronautics and astronautics, the Fédération Aéronautique Internationale (FAI), says that space begins at 100km (62 miles) from the surface of the Earth. NASA, however, sets the edge of space at 80km (50 miles). This means we have two different figures for the number of official space travellers.

According to the FAI, 528 people have been to space, but NASA has the number at 535. As you can see this isn't a large number, with it being possible for all the astronauts in Earth's history to be comfortably seated on a 747 aircraft. Getting into space is still a very privileged experience. This is set to change quite rapidly if the space tourism industry can become established. Currently Virgin Galactic has sold nearly 500 tickets for its first series of flights. While the authorities might be reluctant to call these passengers official astronauts, there will be no denying that they will have been into space.

What was the first man-made object in space?

Sputnik 1 was the first man-made object to orbit the Earth. The tiny satellite was launched by the USSR on 4 October 1957. The first object to reach space altitude was a German V-2 ballistic missile launched on 3 October 1942 from Peenemünde, Germany by a team led by rocket scientist Wernher von Braun. In the aftermath of WWII, the liquid-fuelled V-2 eventually led to the Soviet and American rockets that placed the first satellites into orbit and ignited the beginning of the Space Age.

Is space expanding?

We know that the space around us is expanding as we can see things moving away. But we are unsure if the whole of space is expanding. This is because we can only see so far into our universe. We have an edge that we can see but this isn't necessarily the edge of the universe. Therefore, it is likely that the observable universe is expanding into the space around it.

How do you steer a spacecraft into orbit?

It works according to Newton's third law of motion: For every action there is an equal and opposite reaction. Chemical thrusters, ion propulsion, gyroscopes and reaction wheels are among the methods used to steer spacecraft in orbit. Chemical thrusters are used to rapidly cause changes in orbit. Manoeuvring thrusters for orbital adjustments are powered by rocket fuel. The Shuttle was equipped with two Orbital Manoeuvring System (OMS) pods. The ISS uses gyroscopes and small thrusters to maintain orientation.

How much of the Earth can Hubble see?

The Hubble Space Telescope has been a brilliant addition to astronomers' tools over the last 20 years. It has taken some of the most iconic images of space. People have often wondered if we could turn it around and take some pictures of the Earth. This is an interesting idea as the Hubble telescope was actually based on an existing spy telescope. As a result if you pointed it towards the ground you would achieve an optimal resolution of between 100-150mm (3.9-5.9in). This would make you think we could get some fairly impressive images. If this is the case, then why hasn't Hubble been taking ground pictures? Well, it's because of how fast it is moving. The telescope is moving far too quickly to track a point on the Earth's surface. It can't turn around quickly enough. A point on the Earth's surface would be stretched out into a long streak as Hubble zooms round the Earth at 27,000km/h (17,000mph).

> "Hubble is moving too fast to track the Earth. It zooms round the Earth at 27,000km/h"

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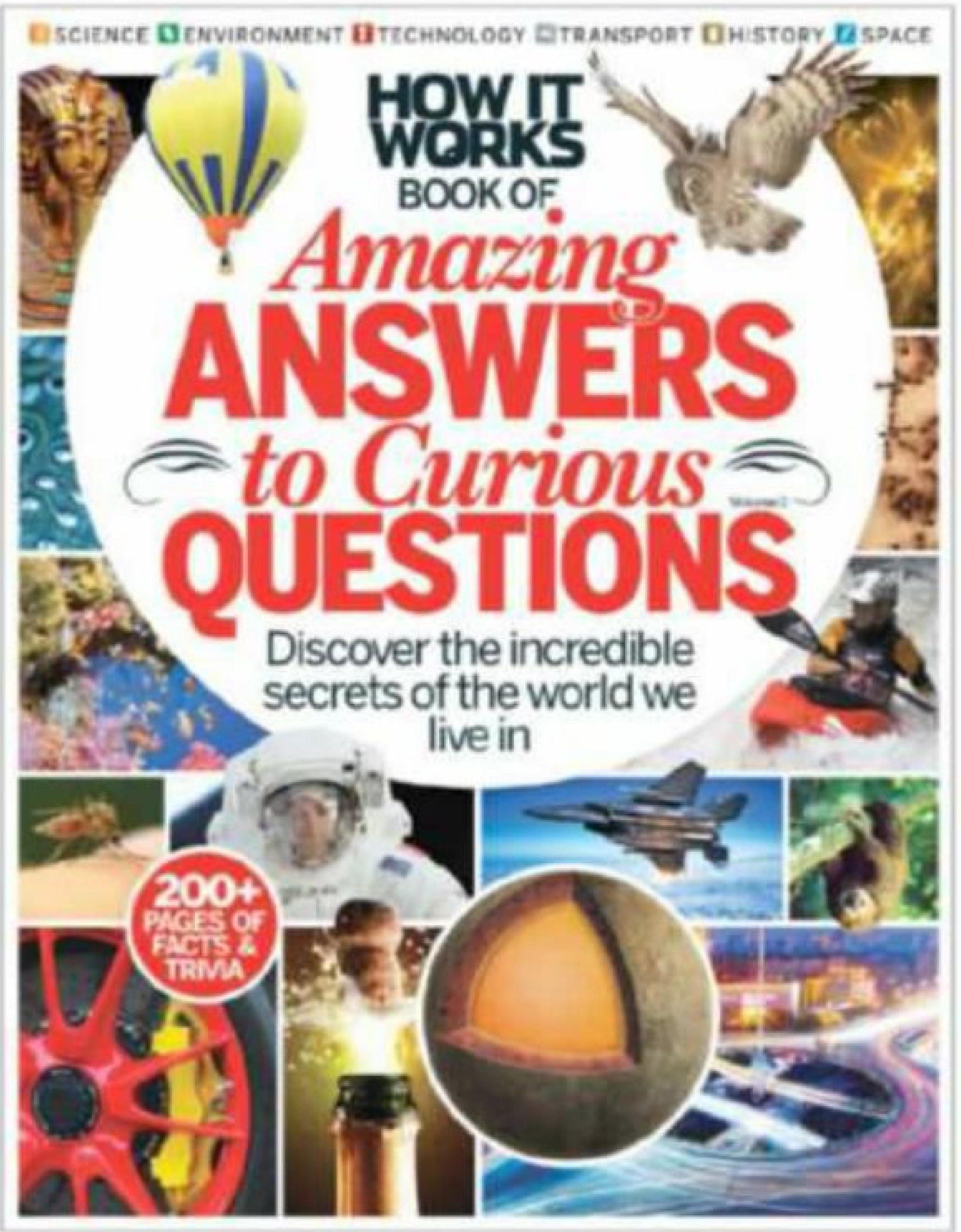
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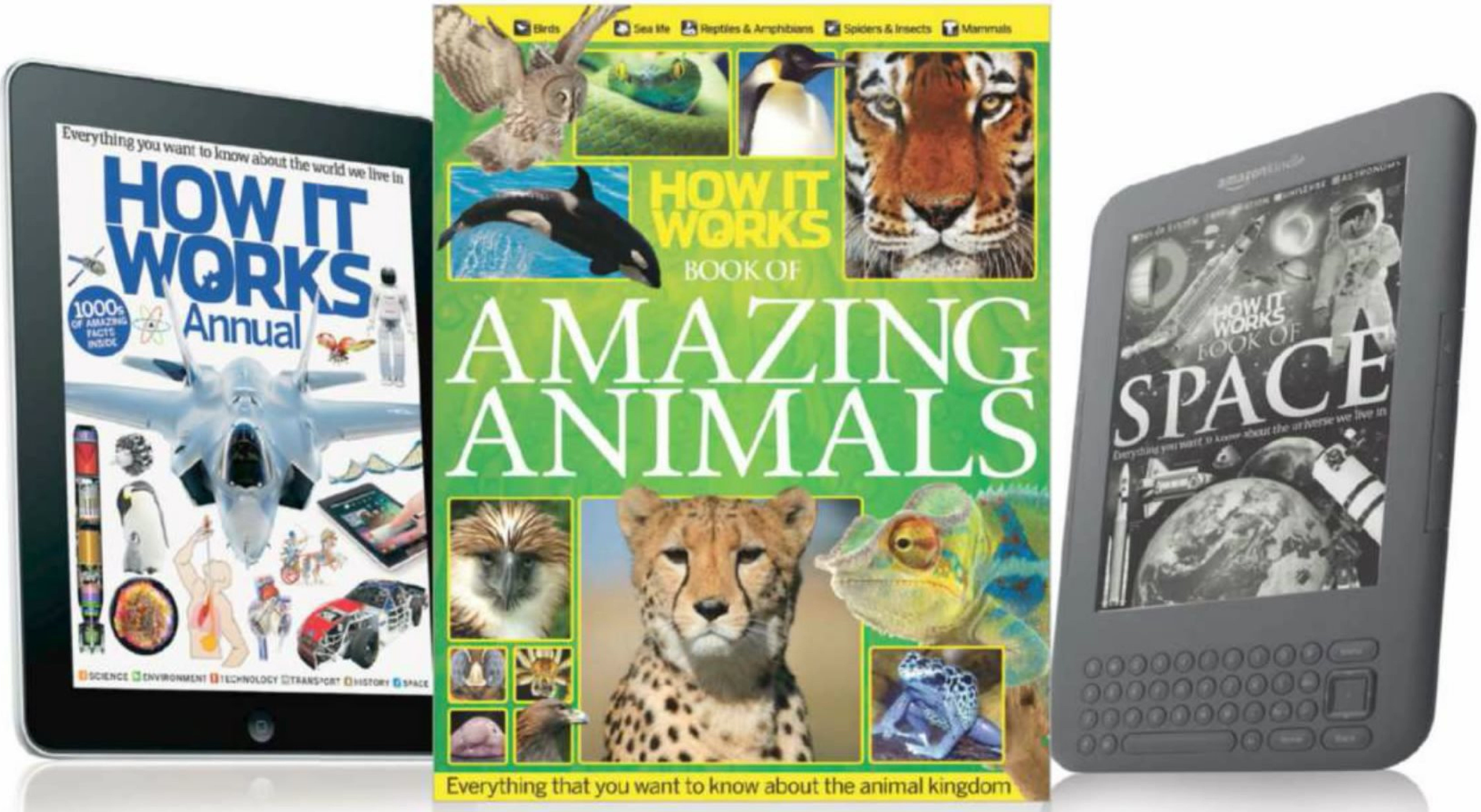

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